REPORT #
RRTAC 87-12

Premining Groundwater Conditions at the Highvale Site

Heritage Fund

Alberta

LAND CONSERVATION AND
RECLAMATION COUNCIL
Reclamation Research
Technical Advisory Committee

Report No. RRTAC 87-12

PREMINING GROUNDWATER CONDITIONS AT THE HIGHVALE SITE

by

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Prepared for

The Reclamation Research Technical Advisory Committee

of

THE LAND CONSERVATION AND RECLAMATION COUNCIL

1987

STATEMENT OF OBJECTIVE

The recommendations and conclusions in this report are those of the authors and not those of the Alberta Government or its representatives.

This report is intended to provide Government and Industry staff with up-to-date technical information to assist in the development of guidelines and operating procedures. The report is also available to the Public so that interested individuals similarly have access to the best available information on land reclamation topics.

ALBERTA'S RECLAMATION RESEARCH PROGRAM

The regulation of surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council executive consists of a Chairman from the Department of the Environment and two Deputy Chairmen from the Department of Forestry, Lands & Wildlife. Among other functions, the Council oversees programs for reclamation of abandoned disturbances and reclamation research. The reclamation research program was established to provide answers to the many practical questions which arise in reclamation. Funds for implementing both the operational and research programs are drawn from Alberta's Heritage Savings Trust Fund.

To assist in technical matters related to the development and administration of the research program, the Council appointed the Reclamation Research Technical Advisory Committee (RRTAC). The Committee first met in March 1978 and consists of eight members representing the Alberta Departments of Agriculture, Energy, Forestry, Lands & Wildlife, Environment and the Alberta Research Council. The Committee meets regularly to update research priorities, review solicited and unsolicited research proposals, arrange workshops and otherwise act as a referral and coordinating body for Reclamation Research.

Additional information on the Reclamation Research Program may be obtained by contacting:

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RECLAMATION RESEARCH REPORT

** 1. RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp.

DESCRIPTION: This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

** 2. RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi, and H.F. Regier. 160 pp.

DESCRIPTION: Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

** 3. RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. 2 vols. L.E. Watson, R.W. Parker, and P.F. Polster. 541 pp.

DESCRIPTION: Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their fitness for use in Reclamation. Range maps, growth habitat, propagation, tolerance, and availability information are provided.

N/A 4. RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp.

DESCRIPTION: This survey is an update of the original report conducted in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

N/A 5. RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stien, R. Leitch, and G. Lutwick. 253 pp.

DESCRIPTION: Presents nine technical papers on the chemical, physical and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites and use of ash as a soil amendment. Workshop discussions and summaries are also included.

N/A 6. RRTAC 82-1: Land Surface Reclamation: An International Bibliography. 2 vols. H.P. Sims and C.B. Powter. 292 pp.

DESCRIPTION: Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system. Vol. 2 comprises the keyword index and computer access manual.

N/A 7. RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp.

DESCRIPTION: This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981 are available from the Alberta Environment Library.

N/A 8. RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp.

DESCRIPTION: Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of recently initiated field trials.

N/A 9. RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp.

DESCRIPTION: Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop reproduction.

N/A 10. RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz. 123 pp.

DESCRIPTION: Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics and resulting water quality. Mitigative measures and priorities were also discussed.

N/A 11. RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Technical Engineering Ltd. 124 pp.

DESCRIPTION: This is a review and analysis of information on planting stock quality, rearing site preparation, planting and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

*** 12. RRTAC 84-1: Land Surface Reclamation: A Review of International Literature. 2 vols. H.P. Sims, C.B. Powter, and J.A. Campbell. 659 pp.

DESCRIPTION: Nearly all topics of interest to reclamation including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

** 13. RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp.

DESCRIPTION: This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

* 14. RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 15. RRTAC 84-4: Soil Microbiology in Land Reclamation. 2 vols. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser, and J.C. Zak. 676 pp.

DESCRIPTION: This is a collection of five reports dealing with reestablishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

** 16. RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz. 416 pp.

DESCRIPTION: Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling shrub propagation and establishment are presented.

* 17. RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 18. RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp.

DESCRIPTION: The report examines the critical issue of settling pond design and sizing and alternative technologies. An executive summary outlines the findings.

** 19. RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp.

DESCRIPTION: Reconstructed soils representing different materials handling and replacement techniques were characterized and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

* 20. RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp.

DESCRIPTION: In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

** 21. RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp.

DESCRIPTION: This report summarizes the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establishe a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

** 22. RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Program. A. Maslowski-Schutze. 71 pp.

DESCRIPTION: This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

* 23. RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp.

DESCRIPTION: The report deals with the availability of water supply in or beneath cast overburden at the Battle River Mining area in east-central Alberta to support post-mining land use. Both groundwater quantity and quality are evaluated.

* 24. RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp.

DESCRIPTION: This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

* 25. RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 26. RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp.

DESCRIPTION: This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe, hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed.

RRTAC Reports 87-1 to 87-11 are in preparation.

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PREFACE

This is one of a series of reports that presents the findings of the Plains Hydrology and Reclamation Project (PHRP), an interdisciplinary study that focuses primarily on hydrologic aspects of reclamation of surface coal mines in the Plains of Alberta. This research has been conducted by the Alberta Research Council, as part of the Alberta Government's Reclamation Research Program. The program is managed by the Land Conservation and Reclamation Council and is supported by the Heritage Savings Trust Fund.

The focus of the PHRP is to develop a predictive framework that will permit projection of success for reclamation and impact of mining on water resources on a long-term basis. The predictive framework is based on an understanding of processes acting within the landscape so that in the future, mine sites that are not totally analogous to those that have been studied can be evaluated as well.

The project involves a holistic approach to reclamation by integration of studies of geology, hydrogeology, and soils, not only in the proposed mining area, but also in the adjoining unmined areas. This approach permits the assessment of impacts and of long-term performance, not only in reclaimed areas, but also in the surrounding area.

The research of the PHRP was directed toward the following two major objectives and eight subobjectives.

Objective A

To evaluate the potential for reclamation of lands to be surface mined. The focus is on features of the landscape that make it productive in a broad sense not restricted to revegetation. This objective was organized into five subobjectives.

1. To assess and evaluate the potential for long-term degradation of reclaimed soils through salt buildup.
2. To assess and evaluate the effectiveness of topographic modification and selective placement of

materials to mitigate deleterious impacts on chemical quality of groundwater.

3. To assess the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations.
4. To evaluate the productivity potential (capability) of post-mining landscapes and the significance of changes in capability as a result of mining.
5. To assess and evaluate limitations to post-mining land use posed by physical instability of cast overburden.

Objective B

To evaluate the long-term impact of mining and reclamation on water quantity and quality. This objective was organized into three subobjectives.

1. To assess and evaluate the long-term alteration of quality of groundwater in cast overburden and surface water fed from mine spoil as a result of the generation of weathering products.
2. To assess and evaluate infiltration, groundwater recharge and groundwater-surface water interactions within cast overburden.
3. To characterize the groundwater chemistry generated within cast overburden.

Studies directed at these objectives began in 1979 at the Battle River site in east-central Alberta. Work began in 1982 at a second study area at Highvale Mine south of Lake Wabamun.

The present report presents the characterization of premining hydrogeologic conditions at the Highvale Site, which is part of the fundamental background information required as part of several of the project's subobjectives, notably Subobjective A-3 (availability of post-mining water supply) as well as all of the

subobjectives under Objective B (long-term impact of mining on water quality and quantity).

This report presents a description of the study of the Highvale Site, followed by a detailed discussion of the premining flow patterns, hydraulic properties, and isotopic and hydrochemical characteristics for five hydrostratigraphic units within the Paskapoo Formation, the underlying sandstone beds of the Upper Horseshoe Canyon Formation, as well as for the glacial drift. As part of this characterization extensive use was made of existing instrumentation, reports, and data prepared by Monenco Consultants Ltd. on behalf of TransAlta Utilities Corporation.

The hydrostratigraphic units studied for the report include the surficial material, through the bedrock overburden and the Ardley Coal Zone, to sandstone horizons, roughly 100 m deep, below the base of mining.

ACKNOWLEDGEMENTS

The Plains Hydrology and Reclamation Project was sponsored by the Reclamation Research Technical Advisory Committee of the Alberta Land Conservation and Reclamation Council, with funding support from the Alberta Heritage Savings Trust Fund. TransAlta Utilities Corporation is acknowledged for providing access to existing reports and information, as well as access to lands for instrumentation. Landowners in the Highvale area are also acknowledged for their co-operation in allowing access to private lands.

1. INTRODUCTION

The Plains Hydrology and Reclamation Project (PHRP) of the Alberta Research Council began its study of the Highvale Mine area in 1982. Forty-two piezometers were installed at 10 sites in the unmined landscape, largely to supplement the existing network of instruments established by TransAlta Utilities Corporation.

Previous work in the Highvale area was done primarily by Monenco Corporation. (Montreal Engineering Ltd.) on behalf of TransAlta Utilities Corporation. The reports that address the premining groundwater conditions are by Ceroici et al. (1982); Montreal Engineering (1978, 1979); and Monenco (1981), although several other reports include discussions related to groundwater conditions.

This report is based on data generated by the Alberta Research Council and others prior to 1983. Data have been collected since that time for TransAlta Utilities Corporation that may alter the findings of this report.

1.1 SITE DESCRIPTION

The Highvale Site is located approximately 60 km west of Edmonton and includes approximately 250 km^2 extending from the southern shore of Lake Wabamun to the North Saskatchewan River (Figure 1). The land is generally undulating to rolling and is presently utilized primarily for agriculture or wildland. The principal topographic features of the Highvale area include Lake Wabamun (elevation 732.2 m above sea level), and a northwest-southeast trending escarpment that reaches an elevation of approximately 800 m above sea level and is situated from 3 to 5 km south of the lake. In the south-central part of the area is a dry lake bed at an elevation of approximately 745 m above sea level. This lake, which was called Low Water Lake before it was drained, is approximately 10 km long and 4 km wide (elongated in a north-south direction).

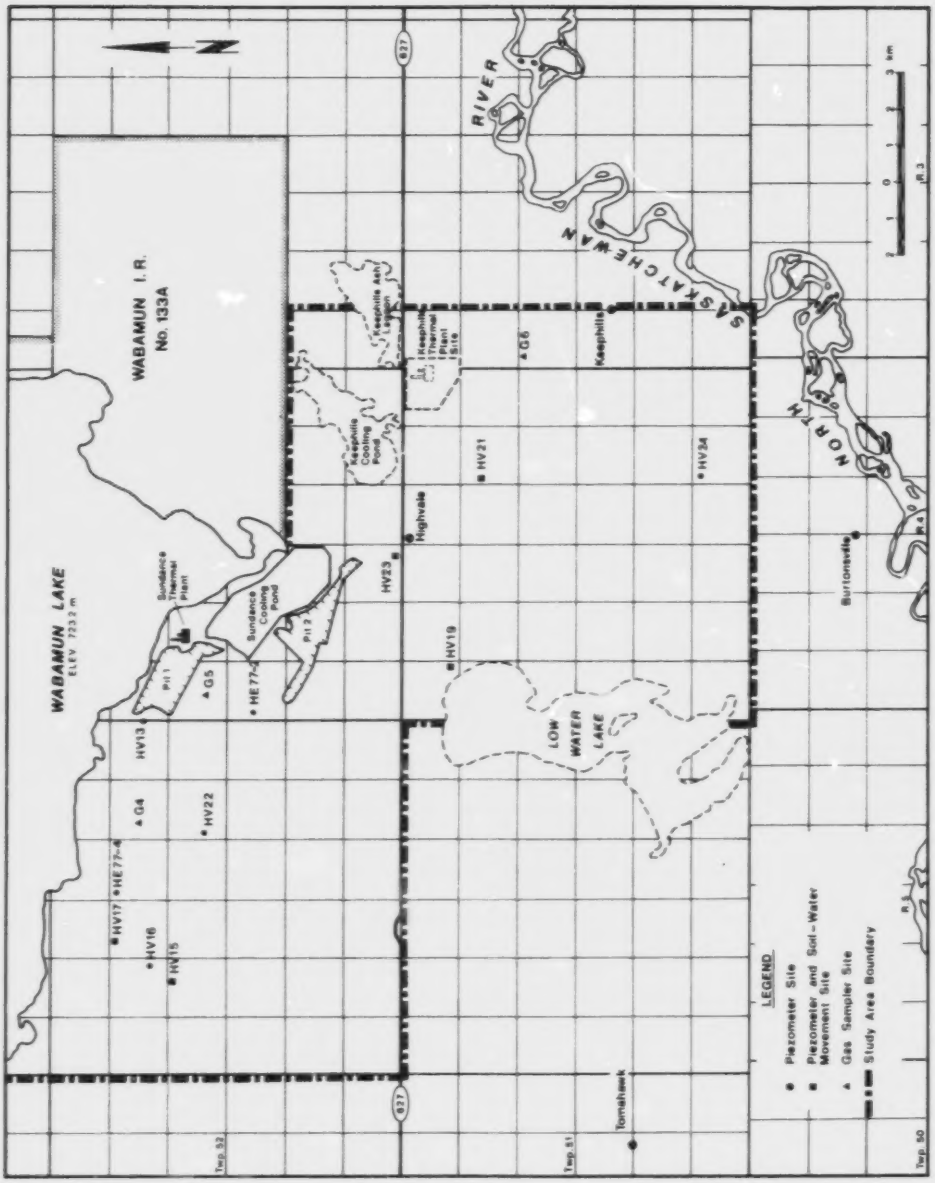

Figure 1. Location of the Highvale project area.

In the southeast part of the study area is an upland, with elevations as much as 840 m above sea level, which drops off toward the North Saskatchewan River in the south, Lake Wabamun in the north, and Low Water Lake in the west.

1.2 GEOLOGY

The bedrock in the Highvale area is of Upper Cretaceous and Paleocene age, and consists of clastic sedimentary rocks of continental origin associated with coal seams. Three stratigraphic units are present (from shallowest to deepest): The Paskapoo Formation (Upper Cretaceous-Paleocene), Battle Formation (Upper Cretaceous), and Horseshoe Canyon Formation (Upper Cretaceous) (Figure 2).

The Paskapoo Formation has three principal components:

1. A basal sandstone and shale unit overlying the Battle Formation;
2. The Ardley Coal Zone; and
3. Bedrock overburden above the Ardley Coal Zone.

The first two of these components combine to form the Scollard Member of the Paskapoo Formation.

The bedrock overburden can be further subdivided into four informal lithostratigraphic units (Maslowski Schutze in press) identified as Units A, B, C, and D (from deepest to shallowest) (Figure 2). Unit A is a generally thin shale bed that lies directly on the coal zone. Unit B is the "Major Sandstone" of the Paskapoo Formation, a predominantly sandstone horizon that is as much as 36 m thick, but averages approximately 20 m thick. The sandstone of Unit B forms the principal premining aquifer in the Highvale area. It is overlain and confined by a predominantly shale aquitard referred to as Unit C. Unit C is as much as 28 m thick, and is overlain by an interbedded siltstone, sandstone, and shale horizon (Unit D) at localities in the study area where the bedrock overburden is generally greater than 50 m thick. The bedrock overburden has been subjected to glacial thrusting and/or deformation over much of the

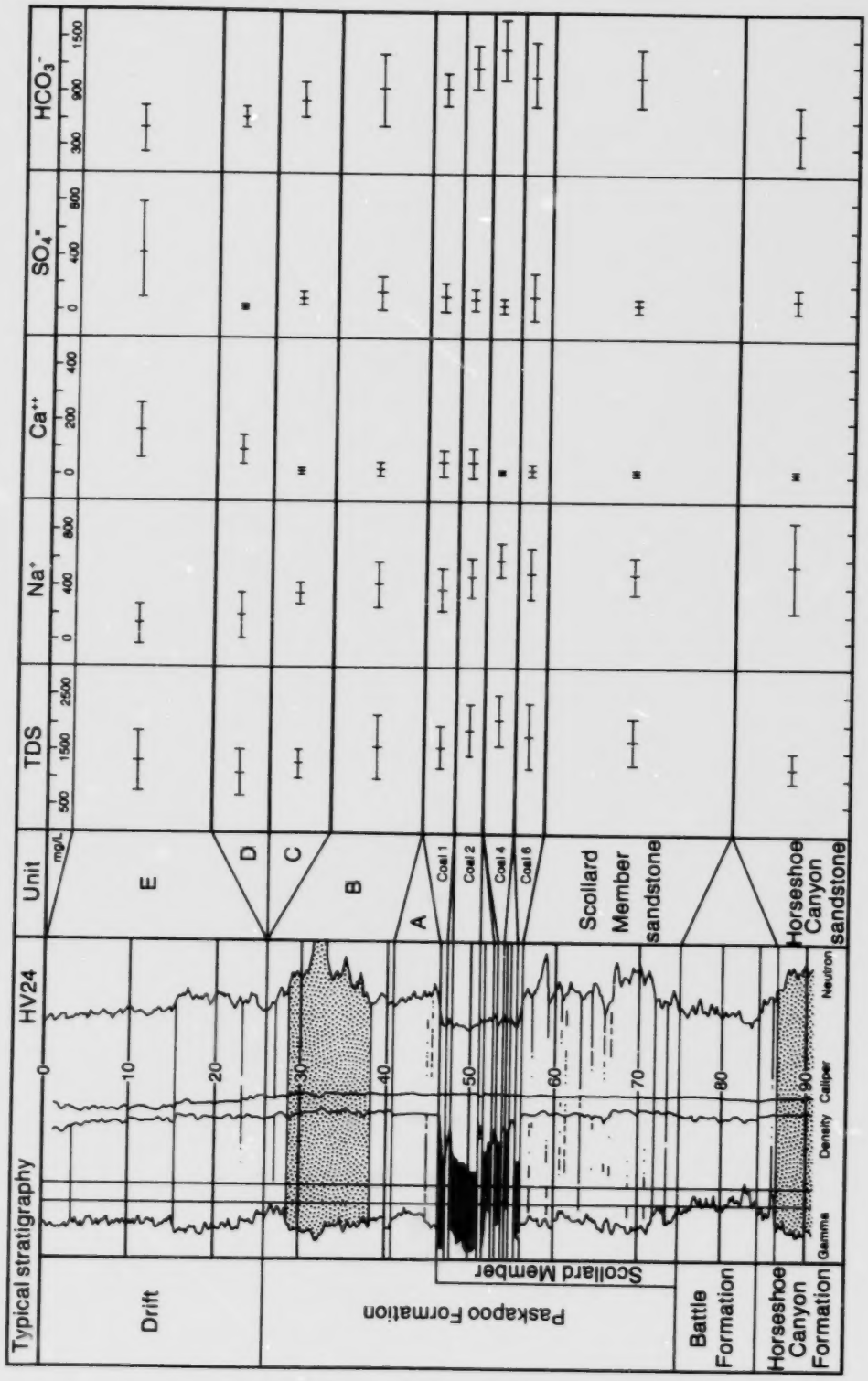

Figure 2. Generalized stratigraphic column and vertical trends in groundwater chemistry.

study area, particularly in the portion of the study area within 8 to 10 km of the south shore of Lake Wabamun.

The Ardley Coal Zone is generally made up of six seams, identified from shallowest to deepest as Coal Seams #1 through #6 (Figure 2). Coal Seams #1 and #2 are the thickest, each averaging about 4 m thick. Coal Seams #3, #4, #5, and #6 range in thickness from 0.4 to 1.3 m.

Underlying the Paskapoo Formation is the Battle Formation (Figure 2), a relatively thin, dense lacustrine shale (Binda and Lerbekmo 1973) that is laterally continuous and forms a regional aquitard.

Below the Battle Formation is the Upper Horseshoe Canyon Formation (Figure 2), which is made up of laterally discontinuous sandstone, siltstone, and shale beds of fluvial origin (Nurkowski and Rahmani in press). In this report only the portion of the Horseshoe Canyon Formation above the deeper Carbon-Thompson Coal Zone is considered. The channel-fill sandstone beds of this unit are local aquifers, but are of limited lateral extent.

2. METHODS OF INVESTIGATION AND SYNTHESIS

This investigation is based on the study of approximately 420 piezometers installed in unmined material at the Highvale study area. Approximately 380 of these piezometers were installed by Monenco Ltd. (Montreal Engineering Ltd.) for TransAlta Utilities; 42 were installed by the Alberta Research Council, Plains Hydrology and Reclamation Project.

2.1 PHYSICAL HYDROLOGY

Analysis of the groundwater-flow regime utilized water-level readings in piezometers to determine hydraulic head (in metres of water above mean sea level) on the basis of stratigraphic units. Single-well response tests were performed on selected piezometers from each stratigraphic unit in order to determine the hydraulic conductivity (Cooper et al. 1967; Hvorslev 1951).

2.2 GROUNDWATER CHEMISTRY

Water samples were collected from most of the piezometers in order to characterize the chemical and isotopic properties of groundwater from each stratigraphic unit. All of the samples were analysed for major ionic constituents (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, Cl^{-}, CO_3^{2-}, HCO_3^{-}, NO_3^{-}) minor constituents (SiO_2, F^{-}), specific conductance, and pH, as well as field analysis of alkalinity, pH, temperature, dissolved oxygen, total iron, and sulfide. Selected samples were also analysed for trace elements, stable isotopes (oxygen-18 and deuterium), and tritium, as discussed below.

2.3 EQUILIBRIUM SPECIATION OF GROUNDWATER

The United States Geological Survey geochemical model WATEQF was used to evaluate the equilibrium speciation of groundwater in the Highvale study area. In almost all cases, the groundwater is slightly undersaturated to saturated with calcite and dolomite. Another important mineral, in terms of saturation status, is gypsum.

Saturation index (SI) is the parameter used to characterize mineral saturation status and is defined as:

$$SI = \log IAP/K_T$$

For gypsum, IAP (ion activity product) is the product of the thermodynamic activity (effective concentration) of Ca^{2+} and SO_4^{2-} at the field temperature. K_T is the theoretical solubility product for gypsum at the field temperature. At saturation, IAP is equal to K_T; therefore, the saturation index is zero. The SI values that are negative represent conditions of undersaturation with respect to gypsum ($IAP < K_T$). Conversely, positive SI values indicate supersaturation with respect to gypsum ($IAP > K_T$).

Another important parameter that is determined from the WATEQF speciation analysis is referred to as the modified selectivity coefficient (K') for calcium-sodium ion exchange. The modified selectivity coefficient is used for an approximation of the calcium-sodium ion exchange characteristics of the aquifer material. Traditionally, ion exchange is described by the selectivity coefficient, K, which for the exchange reaction

$$Ca^{2+} + Na(ad) = 2Na^{+} + Ca(ad)$$

can be defined as:

$$K = ([Na^{+}]^2 N_{Ca})/([Ca^{2+}] N_{Na})$$

where the square brackets indicate thermodynamic activity (effective concentration), (ad) indicates the adsorbed phase and N represents mole fraction of the adsorbed phase (Freeze and Cherry 1979). In natural materials with a large reservoir of exchanger relative to the amount of dissolved species in solution it is possible to define a modified selectivity coefficient (K') as:

$$K' = [Na^+]^2/[Ca^{2+}] = K\ N_{Na}/N_{Ca}$$

for the calcium-sodium exchange reaction (Parkhurst et al. 1980). The K' is essentially a ratio of the dissolved species involved in the exchange reaction, and is approximately constant when the amount of exchangeable sodium and calcium on the solid particles is large enough that exchange with ions in solution has a negligible effect on the reservoir of exchangeable ions. In this case, the mole fractions of sodium and calcium are approximately constant, K is constant, and therefore K' will also be approximately constant. Ion activities from WATEQF are used to calculate K' values from groundwater samples. Typical K' values at the Highvale Site range from 0.01 to 9.0, with most values being greater than 1.0 reflecting the dominance of sodium in the groundwater, a characteristic that results primarily from ion exchange associated with the ubiquitous sodic montmorillonite in the bedrock material.

2.4 TRACE ELEMENTS

Selected groundwater samples from the premining area of the Highvale Site were analysed for the elements antimony (Sb), arsenic (As), boron (B), cadmium (Cd), cobalt (Co), copper (Cu), lead (Pb), mercury (Hg), and selenium (Se). Appendix 8.1 is a listing of the trace element analyses (by stratigraphic unit) for all groundwater samples from the Highvale Site.

2.5 TRITIUM ANALYSES

Selected surface and groundwater samples from the Highvale project area were also analysed for tritium content. Tritium is the radioactive isotope of hydrogen (atomic mass = 3 amu) present in precipitation. Prior to the start of atmospheric testing of thermonuclear bombs in 1952, the levels of tritium in precipitation were in the order of 5 to 20 tritium units (TU, where 1 TU = 1 ^3H atom in 10^{18} hydrogen atoms) (Payne 1972). Tritium produced by atmospheric testing of thermonuclear devices between 1953 and 1967

caused tritium in precipitation measured in Edmonton to reach levels as high as 4022 TU in 1963, with levels declining in subsequent years (Brown 1970). The half-life of tritium is 12.3 years; therefore, water that recharged the groundwater system prior to 1953 will have tritium concentrations of less than 5 TU (Egboka et al. 1983). It is therefore possible to distinguish relatively recent groundwater (recharged after 1953) from relatively old groundwater (recharged prior to 1953) on the basis of tritium content.

Water samples collected for tritium were analysed at the Environmental Isotope Laboratory of the Earth Sciences Department, University of Waterloo, Ontario. Measurements were made by direct liquid scintillation counting of a water-Instagel cocktail prepared from each sample. Analytical precision is at best 8 TU using this technique. At the 95% confidence level (1.96 standard deviations) analytical precision is in the order of 16 to 20 TU. Consequently, samples with reported tritium values below 20 TU are probably pre-1953 waters. Because of potential contamination and unpredictable background radiation levels, samples with 20 to 30 tritium units are questionable. Within this group (20 to 30 TU), those samples from deeper aquifers probably represent pre-1953 recharge water; if the samples are from shallower aquifers, the tritium values are inconclusive, but probably represent post-1953 water.

2.6 STABLE ISOTOPE ANALYSES

Oxygen-18 and deuterium (^{2}H) are the heavy, stable isotopes of oxygen and hydrogen, respectively, that are present in water. Precipitation in northern latitudes is depleted in both isotopes, compared to their concentrations in sea water. The extent of this depletion is expressed as the ratio (R) of $^{18}O/^{16}O$ and $^{2}H/^{1}H$ in precipitation compared to the ratio of a standard referred to as SMOW (standard mean ocean water). The units are called delta (δ) units, and are expressed in per mille (parts per thousand), where:

$$\delta^{18}O‰ = (R_{sample} - R_{SMOW})/R_{SMOW} \times 1000$$

As a general rule the magnitude of the depletion of ^{18}O and deuterium in sea water increases with colder temperatures; therefore, winter precipitation shows a greater depletion (^{18}O and deuterium values are more negative) than summer precipitation. Consequently, it is possible to estimate the time of year in which groundwater recharge has occurred if it is meteoric in origin.

It has been found that there is a linear relationship between values of $\delta^{18}O$ and $\delta^{2}H$ in precipitation (Craig 1961). As a result, on a plot of $\delta^{2}H$ vs $\delta^{18}O$ (Figure 3) samples from precipitation plot along a straight line, referred to as the meteoric water line. Craig (1961) defined this meteoric water line as:

$$\delta^{2}H = 8\delta^{18}O + 10$$

Oxygen-18 and deuterium can also be used to differentiate meteoric water from standing surface water because of the isotopic fractionation that occurs during evaporation. As water evaporates from a standing surface water body, water molecules containing ^{16}O or ^{1}H are more easily transferred to the vapour phase than are water molecules containing the heavier isotopes. Consequently, the water that remains is enriched in the heavier isotopes, and the relationship between ^{18}O and deuterium is changed relative to precipitation such that on a plot of $\delta^{2}H$ vs $\delta^{18}O$ the values do not fall along the meteoric water line, but rather plot to the right of the meteoric water line (Figure 3). Samples taken at time intervals from an evaporating water body will also form a straight line on a plot of $\delta^{2}H$ vs $\delta^{18}O$ (Figure 3) but the evaporation line will have a lower slope (2 to 5) than meteoric water line (slope = 8) and will intersect the meteoric water line at the isotopic content of the surface water prior to evaporation (Fontes 1980).

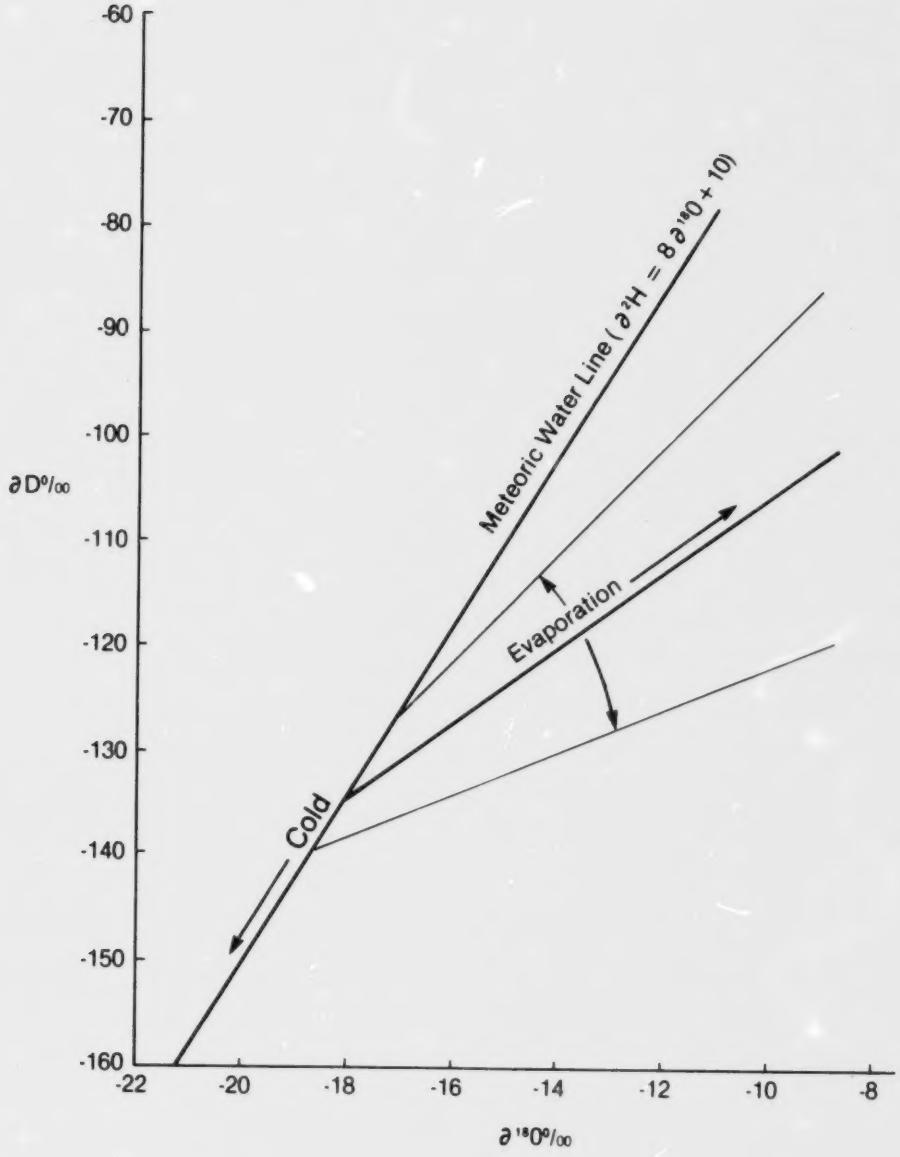

Figure 3. Generalized plot of deuterium per mille SMOW vs oxygen-18 per mille SMOW.

3. OVERVIEW OF GROUNDWATER-FLOW PATTERNS AND CHEMISTRY

3.1 GROUNDWATER-FLOW PATTERNS

The groundwater-flow patterns in the Highvale study area are controlled by topography and the outcrop/subcrop pattern of shallow hydrostratigraphic units. In the portion of the groundwater-flow system in or above the Ardley Coal Zone, flow is occurring from the uplands south of Lake Wabamun, in a north or northeasterly direction, toward the lake. The hydraulic head in the coal and overburden aquifers is in almost all cases above the level of Lake Wabamun. The coal zone and overburden aquifers generally subcrop south of the lake. Therefore, although flow is directed toward Lake Wabamun, discharge to the lake directly from these aquifers is probably not occurring, except in places where the coal zone subcrops below the lake. However, it is likely that Lake Wabamun is directly receiving some groundwater discharge from shallow surficial or bedrock aquifers.

In the southeast part of the study area, groundwater flow in the coal zone and overburden is from the uplands toward the subcrop, resulting in flow directions ranging from southward to eastward. The role of Low Water Lake, in the central part of the study area, varies with the scale of the flow system. It appears to be a discharge area for shallow bedrock overburden and drift aquifers, but may also be acting as a recharge source for the coal zone and deeper aquifers.

The North Saskatchewan River is the regional groundwater drain for the southern part of the study area. A local groundwater divide running east-west bisects Low Water Lake and the uplands to the east, and separates groundwater flow directed north toward Lake Wabamun from that directed south toward the North Saskatchewan River.

The vertical hydraulic gradients at the Highvale Site indicate that the site is predominantly a recharge area as illustrated in the hydrogeological cross section of Figure 4. Downward vertical gradients are present in virtually all settings

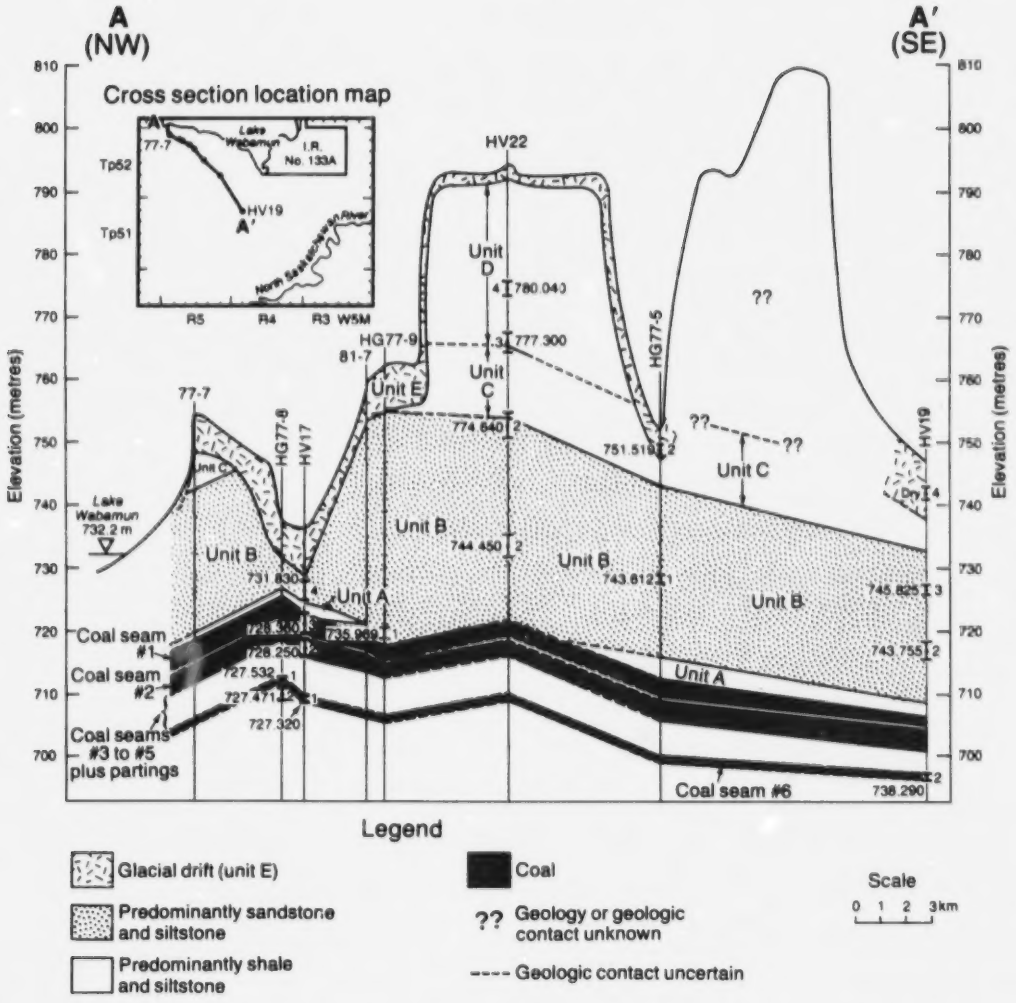

Figure 4. Hydrogeologic cross section of the Highvale project area.

except perhaps in very local settings, where flow systems are shallow. Sites situated in lowland settings generally considered to be "discharge" areas are in fact recharge areas on the intermediate to regional scale. In most cases in this type of setting the water table is close to ground surface, but groundwater flow is directed downward, although the vertical hydraulic gradients may be lower than in upland recharge areas. The exception to this general statement is the area corresponding to the coal and overburden sandstone subcrop along the south shore of Lake Wabamun. In this setting, where the coal subcrop occurs below an escarpment approximately 70 m in height, groundwater discharge conditions are indicated. Vertical hydraulic gradients in this setting are generally low (less than 0.2) and in some cases are upward-directed. It is likely that, under these conditions, groundwater-flow directions are lateral, with discharge occurring along the subcrop face.

Groundwater recharge in the Highvale study area is derived primarily from downward infiltration of water in upland areas and temporary ponding in shallow depressions. Because of the general absence of surface ponds, pond leakage is generally a negligible component of groundwater recharge, except in the vicinity of the Keephills Plant area where numerous permanent ponds are present. For the Highvale study area, excluding the Keephills Plant area, the 1983 groundwater recharge rate was 0.8 cm per year (0.8% of annual precipitation), based on the analysis of water-table hydrographs and soil moisture measurements. No analysis of groundwater recharge for the Keephills Plant area was conducted.

3.2 CHEMICAL COMPOSITION AND EVALUATION OF GROUNDWATER

The chemical makeup of groundwater in the Highvale project area is summarized by stratigraphic unit in Figure 2. In general, the groundwater is dominated by sodium and bicarbonate, with total dissolved solids (TDS) in the range from 1000 to 2000 mg/L.

In the drift, the groundwater composition is more variable than in the bedrock, with the highest levels of calcium and sulfate

found in this stratigraphic unit. There is a tendency for the concentration of both calcium and sulfate to decrease with depth, whereas concentrations of sodium and bicarbonate tend to increase with depth. This trend is common in shallow groundwater systems in the plains and is probably related to a loss of calcium and increase in sodium by ion exchange within the bedrock, together with sulfate reduction, which produces bicarbonate. In addition, the removal of calcium from the aqueous phase by ion exchange may disrupt the equilibrium of the groundwater with respect to calcite, causing calcite dissolution and a corresponding increase in dissolved bicarbonate.

Within the Ardley Coal Zone, Coal Seams #1 to #4 display a trend in water chemical makeup that fits the overall pattern; that is, increasing sodium and bicarbonate with depth, and decreasing calcium and sulfate. The water in Coal Seam #6 is somewhat lower in TDS, sodium and bicarbonate than Coal Seams #2 and #4, but higher in sulfate. The chemical characteristics of water in Coal Seam #6 are very similar to those in the overburden sandstone (Unit B).

3.3 TRACE ELEMENTS

Sixty-five groundwater samples from eight stratigraphic units in the Highvale project area were analysed for eight trace elements; arsenic, cadmium, cobalt, copper, mercury, lead, antimony, and selenium. Boron was also analysed in two of the samples. The results of the analyses are listed in Appendix 8.1 and are summarized in Table 1. In all cases, the concentration of these trace elements was very low to nonexistant.

A summary of the health effects and recommended limits for trace elements analysed for is given in Table 2 (McNeely et al. 1979).

None of the groundwater samples analysed was found to contain mercury, antimony, or selenium at detection limits of 0.5 ppb.

Table 1. Summary of trace element analyses of groundwater samples.

Element	Number Analysed	Number Detected	Number Exceeding Limit for Irrigation or Human Consumption
Arsenic (As)	65	60	0
Cadmium (Cd)	65	3	0
Cobalt (Co)	65	56	0
Copper (Cu)	65	64	0
Mercury (Hg)	65	0	0
Lead (Pb)	65	58	0
Antimony (Sb)	65	0	0
Selenium (Se)	65	0	0
Boron (B)	2	2	0

Both samples analysed for boron were found to contain the element, at levels of 0.63 mg/L at Site HE77-4-1 (Unit B) and 0.15 mg/L at Site KA81-3-2 (Scollard Member Sandstone).

Only three samples were found to contain cadmium at a detection limit of 0.5 ppb. The maximum cadmium concentration was 0.7 ppb, which occurred in two of the samples; in the remaining samples, cadmium concentration was at the detection limit.

Approximately 92% of the samples were found to contain detectable arsenic. In only four cases did the concentration exceed 10 ppb, with the maximum concentration being 20.5 ppb, which is still considerably lower than the recommended maximum.

Fifty-six of the 65 samples contained cobalt, at a detection limit of 0.5 ppb. The maximum concentration obtained in any sample was 20 ppb, which occurred in one drift sample and one sample from Coal Seam #6.

Ninety-eight percent of the samples (64 out of 65) were found to contain copper, at a detection limit of 0.5 ppb. The maximum concentration of copper found, at 21.0 ppb, is still well below the recommended maximum of 1000 ppb.

Table 2. Summary of trace element characteristics.

Element	Physiological Effects	Recommended Maximum (all values in mg/L)	References
Antimony (Sb)	- accumulates in liver - harmful to heart	10.0	Tai 1970
Arsenic (As)	- accumulates in kidneys	50.0*	International Joint Commission 1977
Boron (B)	- harmful to Central Nervous System - high concentrations affect plants	5.0* 1.0**	Department of National Health and Welfare 1979
Cadmium (Cd)	- accumulates in arteries, kidneys and lungs - affects plant growth and suitability as food source	5.0*	Department of National Health and Welfare 1979
Cobalt (Co)	- not generally toxic - essential trace nutrient for plants - toxic to some plant species	50.0**	Environmental Studies Board 1973
Copper (Cu)	- essential trace nutrient - toxic at high concentrations or after prolonged ingestion	1000.0*	Department of National Health and Welfare 1979
Lead (Pb)	- toxic to animals and man - accumulates in skeletal material	50.0**	Department of National Health and Welfare 1979
Mercury (Hg)	- highly toxic to animals and plants - accumulates in the kidneys and liver	1.0*	Department of National Health and Welfare 1979
Selenium (Se)	- may be carcinogenic - accumulates in man and animals - moderately toxic to plants	10.0*	Department of National Health and Welfare 1979

* Drinking water.
** Crop application limit.

At a detection level of 0.3 ppb, 58 samples were found to contain lead. The maximum lead concentration, 6.2 ppb, was found in a sample from Coal Seam #2. This level is well below the recommended maximum for lead of 50 ppb.

4. PREMINING HYDROGEOLOGY

4.1 DRIFT

The analysis of groundwater conditions in drift materials in the Highvale area is complicated by the highly localized nature of the flow systems and the sparse instrumentation. Consequently, water-table maps or piezometric-surface maps, which require relatively closely-spaced instrumentation in this kind of setting, are not used.

The depth of the water table below ground surface in the drift is a parameter of interest, since it provides an indication of the long-term, steady-state condition that will be the basis for comparison with the post-mining condition. In the area south of Lake Wabamun, water-table data from the drift are limited. Available data for this area indicate that the depth to water table is from 1.1 to 4.4 m below ground surface. Most of the available data for the drift are from the northeast part of the study area, east of the erosional limit of the coal in the area of the Keephills cooling pond and ash lagoon. The water table in this area is typically 3 to 8 m deep, although farther west, near the Sundance Cooling Pond, the water table is closer to ground surface, with depths ranging from 0.9 to 3.2 m. In the Keephills area somewhat more data are available within the limit of mining than for the Highvale Mine area, and here the depth to water table ranges from 0.5 to 6.4 m below ground surface, with a mean depth of 2.3 m (standard deviation = 1.9, based on seven wells). Within the area of Low Water Lake the water table is very close to or at ground surface. The depth to water table ranges from 1.6 m below ground surface to 0.4 m above ground surface, with a mean depth of 0.52 m below ground surface (n = 14, standard deviation = 0.59). In the Low Water Lake area, upward-directed vertical hydraulic gradients are commonly observed between the deeper drift (or shallow bedrock) and the shallow drift. In some cases these upward gradients result in potentiometric surfaces within the drift that are above ground surface. Low Water Lake, therefore, is in many

places acting as a discharge area for the shallow groundwater-flow system within the drift and shallow bedrock.

The chemical characteristics of groundwater from the drift are described on the basis of samples collected primarily from the area north and east of the coal subcrop, as a result of the absence of wells suitable for sampling in other areas. The chemical makeup of water from the drift is generally calcium-magnesium-bicarbonate to calcium-magnesium-sulfate, with TDS ranging from 400 to 2200 mg/L (Figures 5, 6, and 7). There is an overall tendency for salinity to increase with increasing sulfate and sodium content, with the lowest salinity of about 400 mg/L associated with the calcium-magnesium-bicarbonate water, and the highest salinity of 2000 to 2200 mg/L associated with the calcium-magnesium-sulfate water. Within a given range of anionic composition, for example, 75 to 90% bicarbonate and 10 to 25% sulfate, the salinity of the drift groundwater increases with increasing sodium content, from 400 mg/L at less than 10% sodium up to 1500 mg/L at 80% sodium.

In almost all cases, groundwater from the drift at Highvale is slightly undersaturated with gypsum. The mean gypsum SI value for drift groundwater is -0.828, with a standard deviation of 0.767. Individual SI values range from a low of -1.87 to a maximum of 0.866 at Site KA81-16, the only site at which conditions of supersaturation with gypsum are present. The drift groundwater is significantly closer to gypsum saturation than any of the bedrock materials in which the mean gypsum SI values range from -2.4 to -3.2. This reflects the higher calcium concentrations in the drift, which are derived from the abundant calcite, dolomite, and secondary gypsum. In addition, sulfate concentrations in the drift groundwater are elevated due to the dissolution of secondary gypsum within the soil zone during recharge events, and the oxidation of reduced forms of organic and sulfide sulphur near the water table.

The modified selectivity coefficient (K') values of the drift also reflect a more calcic material compared to bedrock. The mean K' value of 0.031 (standard deviation = 0.079, n = 10) indicates

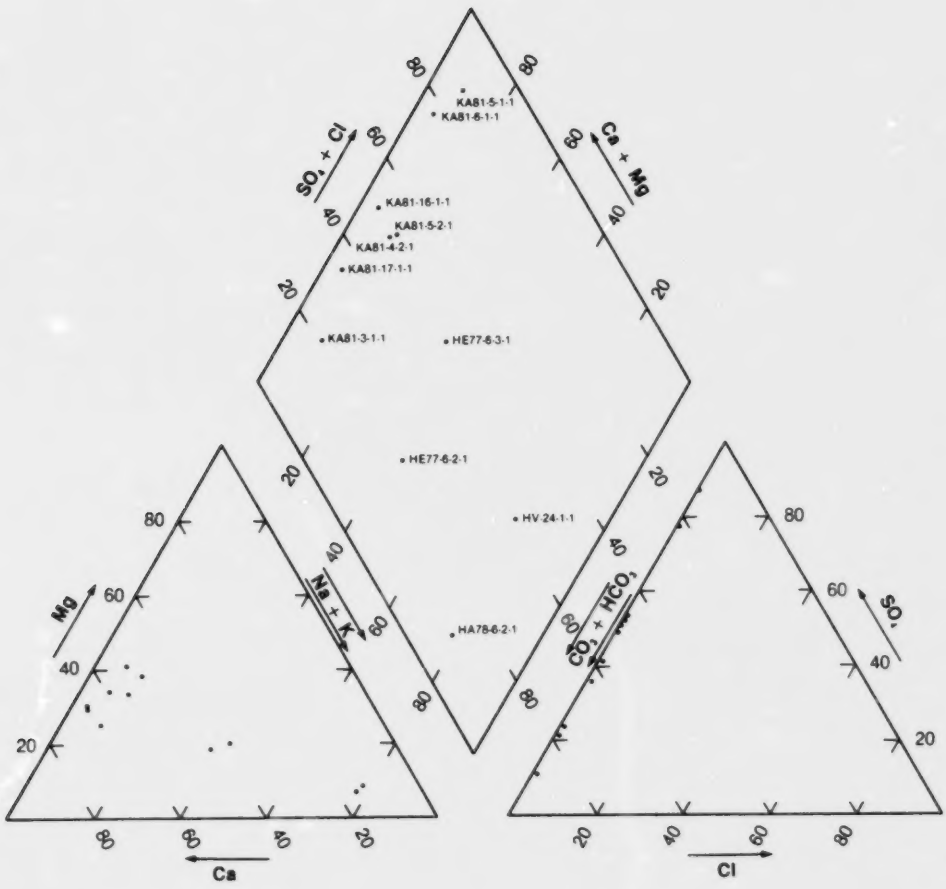

Figure 5. Piper trilinear diagram for groundwater samples from the drift.

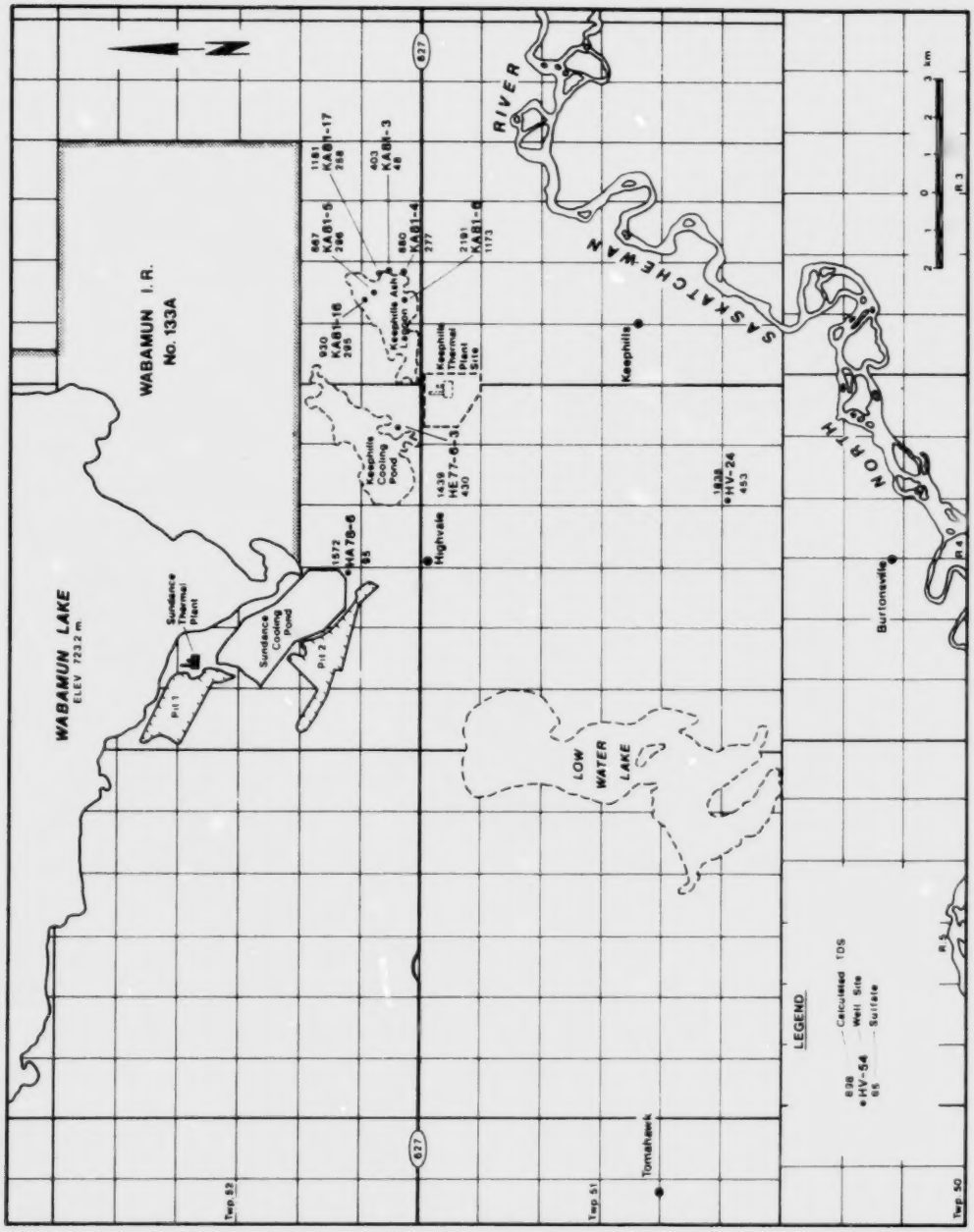

Figure 6. Concentration of total dissolved solids and sulfate in groundwater from the drift.

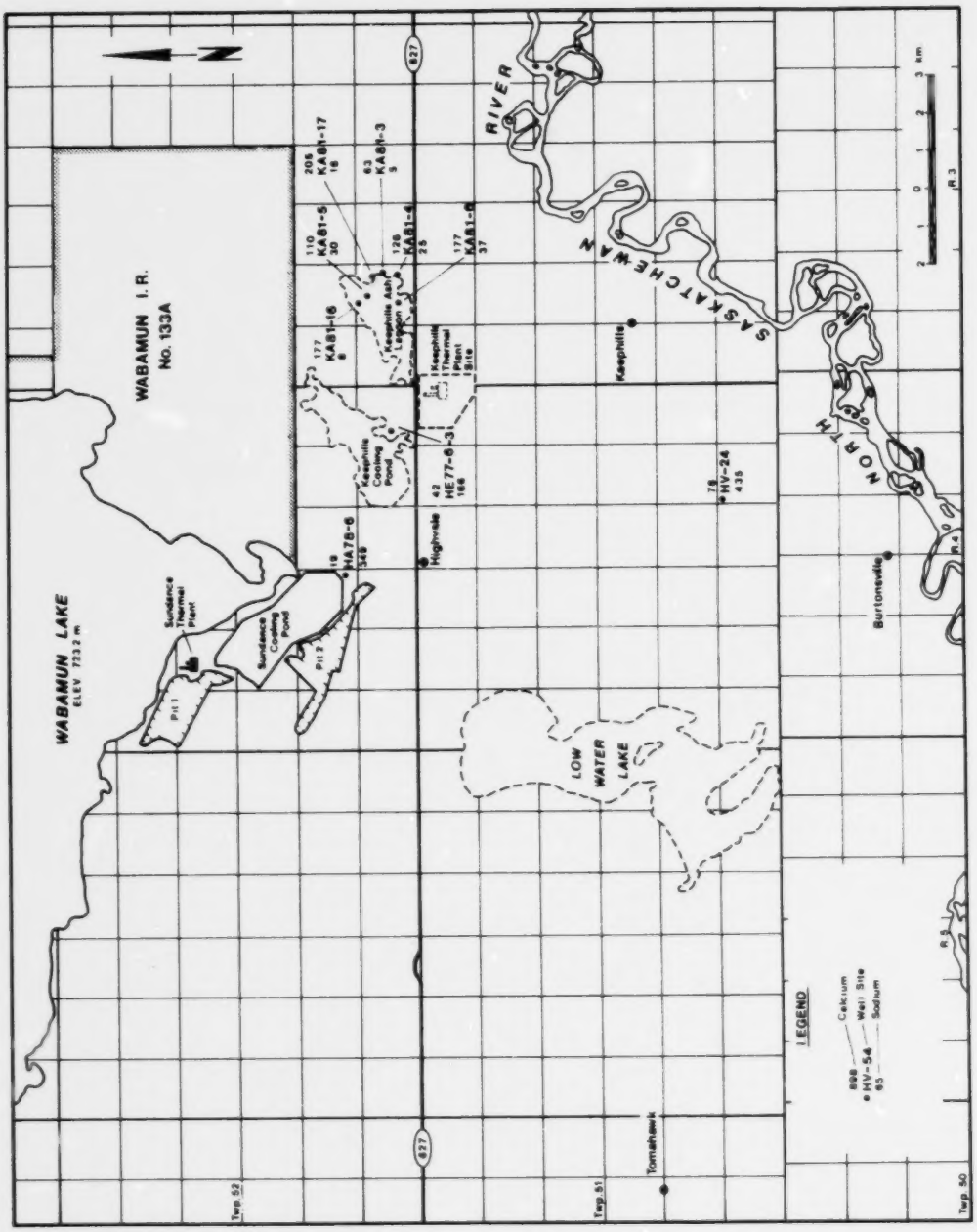

Figure 7. Concentration of calcium and sodium in groundwater from the drift.

that there is relatively little preference for adsorption of calcium over sodium in the drift material. The range of K' values, from 4.12×10^{-5} to 0.268, also shows that there is little influence from calcium-sodium exchange on the groundwater in the drift.

The recharge source of the drift groundwater is primarily meteoric, with one significant exception. On a plot of deuterium versus oxygen-18 (Figure 8) most of the samples cluster around the meteoric water line, in the vicinity of -142 per mille deuterium, -19 per mille ^{18}O. This group is typical of most groundwater from the Highvale area, and represents recharge from snowmelt and spring rainfall events. A second group clusters around -103 per mille deuterium, -11 per mille ^{18}O. This group has evaporative isotopic characteristics that are typical of pond water in the Highvale area. The wells belonging to this group are located in an area of numerous ponds, within the confines of and adjacent to the Keephills Ash Lagoon, and indicate that surface water from the ponds has penetrated the drift to significant depths (7 to 11 m). Water level data suggest that downward hydraulic gradients are present below these ponds, as commonly found in the Highvale project area. The fact that there appears to have been little mixing of the pond recharge water with isotopically lighter meteoric water suggests that these ponds are a significant recharge source, at least in that immediate area. Drift groundwater from Sites KA81-17 and KA81-13 is intermediate in isotopic composition between the group of meteoric source samples and the pond source samples and reflects a mixing of waters from the two sources, with pond water making up approximately 25 to 40% of the total groundwater recharge.

4.2 BEDROCK OVERBURDEN

The bedrock overburden is informally subdivided into four lithostratigraphic units, as previously described, that are referred to as: (1) Unit A, the roof shale overlying the coal zone; (2) Unit B, massive overburden sandstone; (3) Unit C, predominantly shale strata overlying Unit B; and (4) Unit D, predominantly

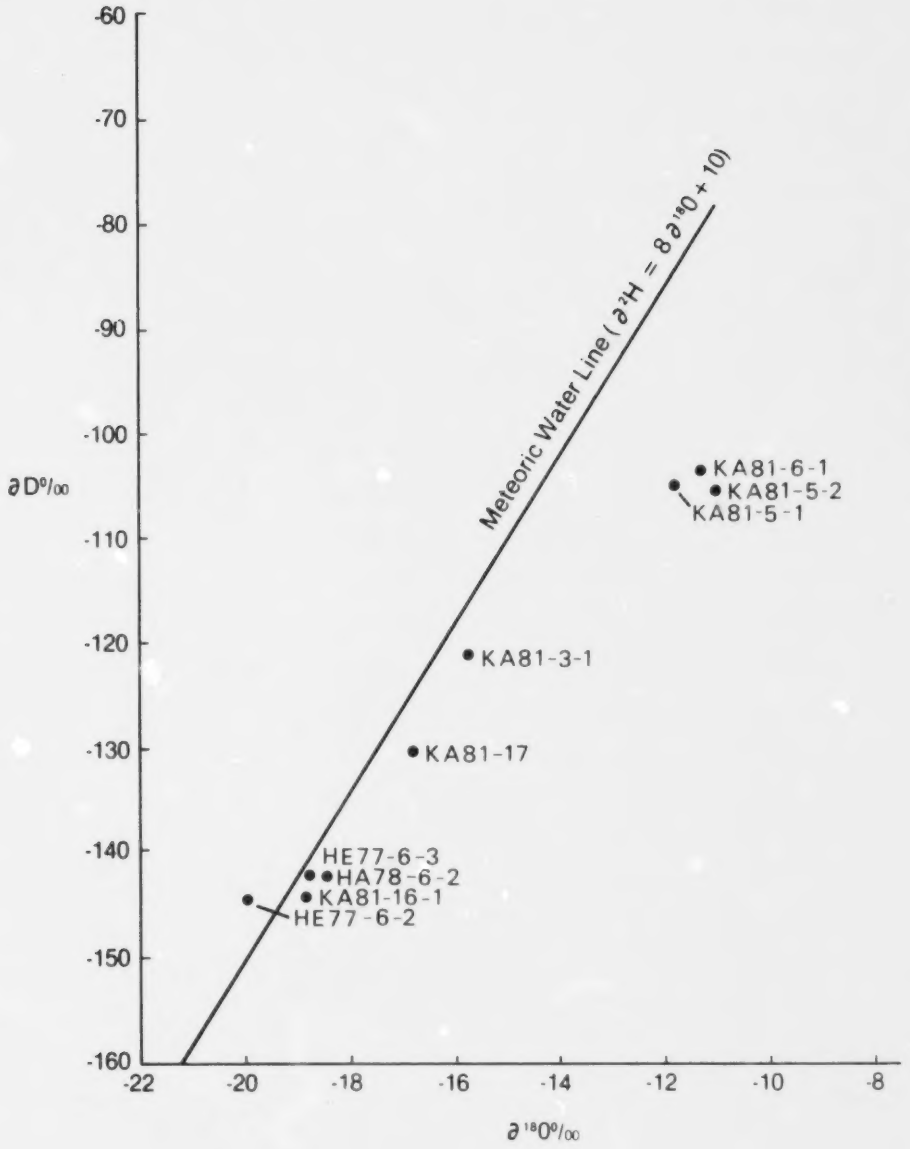

Figure 8. Deuterium versus oxygen-18 for groundwater samples from the drift.

siltstone strata. The great majority of instrumentation is completed in the sandstone of Unit B, although a small number of piezometers have been completed in Units C and D to provide some representation of the vertical hydraulic and hydrochemical trends within the bedrock overburden.

Groundwater-flow patterns within Unit B of the bedrock overburden are illustrated by the piezometric surface map for this unit (Figure 9). At sites where more than one piezometer has been completed within the sandstone of Unit B, head differences of 0.5 to 3 m have been observed, with downward vertical hydraulic gradients typically in the order of 0.05 to 0.5. Because of the thickness of this unit and because the piezometers are completed at different depths within the sandstone from one site to another, it is not possible to separate the effects of lateral changes in hydraulic head from vertical changes in head within the unit. Consequently, the hydraulic heads used to construct the piezometric surface map should be viewed as approximate only. Similarly, the groundwater-flow patterns inferred from this map may represent general trends, but cannot be taken too rigorously.

The general direction of groundwater flow in the sandstone of Unit B in the Highvale area is to the north or northeast, toward the outcrop along the south shore of Lake Wabamun (Figure 9). An eastward component of flow, toward the mine excavation, is present in the area west of Pits O1 and O2. In the vicinity of the Hamlet of Highvale, flow is to the southwest toward Low Water Lake. Within Low Water Lake, the piezometric surface in Unit B is less than 1 m below ground surface at several sites, and even above ground surface at a few sites. Water levels from several Monenco sites in Low Water Lake indicate that upward-directed vertical hydraulic gradients commonly occur between the shallow bedrock and the drift, and in some cases the water level in these units is above ground surface. At sites where vertical hydraulic gradients are downward, their magnitude is generally small. Consequently, in some places Low Water Lake is acting as a discharge area for the shallow bedrock

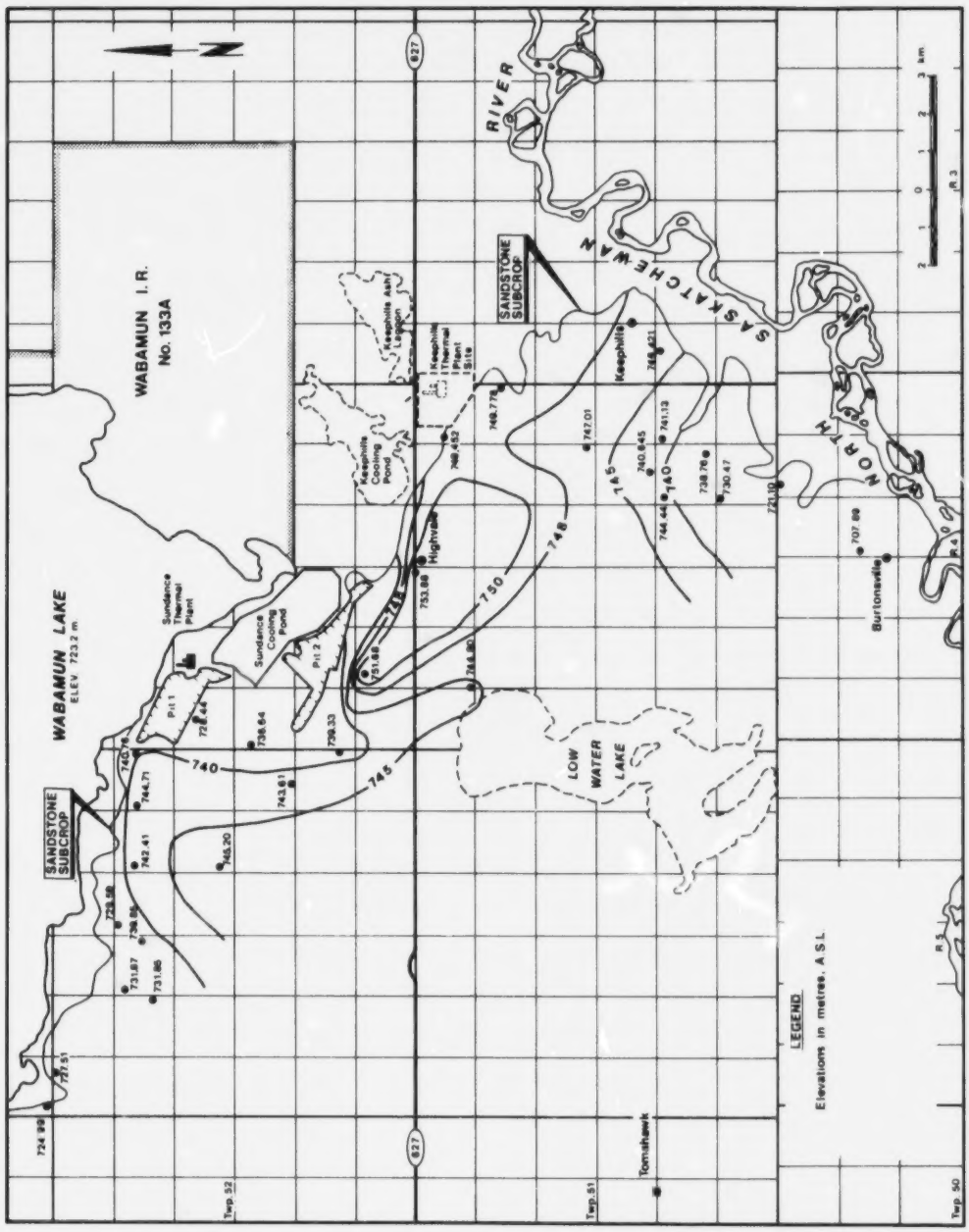

Figure 9. Piezometric surface map for the sandstone of Unit B, bedrock overburden.

overburden. In other places within Low Water Lake, the vertical hydraulic gradients are directed downward and are of increasing magnitude with depth, indicating that the deeper overburden and coal zone are being recharged by the shallow groundwater and surface water in Low Water Lake.

In the Keephills area, groundwater flow in the sandstone of Unit B is to the south and southeast, indicating that the subcrop or outcrop of the sandstone along the North Saskatchewan River has a much greater influence on groundwater flow than does the subcrop north of the Village of Keephills.

The finer-grained Units C and D overlying the sandstone of Unit B have hydraulic heads that are successively higher moving up the stratigraphic column. This reflects downward vertical hydraulic gradients that range from 0.1 to 1.6. The log mean hydraulic conductivity of the sandstone of Unit B is 8.0×10^{-6} m/s, based on single-well response tests from eight piezometers (log standard deviation = 1.875). In Unit C the hydraulic conductivity determined from one test is 3.9×10^{-8} m/s, a value that is toward the high end of typical values for shale. In Unit D the log mean hydraulic conductivity is 4.1×10^{-5} m/s, based on tests from three piezometers (log standard deviation = 0.960). These values suggest that most of the hydraulic head loss occurring in the vertical dimension will take place within the shale of the Unit C horizon. It is surprising that the interbedded siltstone and shale strata of Unit D have a higher hydraulic conductivity than the sandstone of Unit B. This is probably a result of fracturing of the rock of Unit D, related to glacially induced stresses that disturbed shallow bedrock over much of the study area (Fenton et al. 1983).

The groundwater from the bedrock overburden typically contains sodium as the principal cation, with bicarbonate as the dominant anion and a minor sulfate component. Salinities range from 700 to 2300 mg/L. In the shallowest bedrock horizon, Unit D, two principal types of groundwater are present (Figures 10 and 11). The first is a low salinity, calcium-magnesium-bicarbonate type water,

with TDS in the range of 700 to 850 mg/L. Although the composition and salinity of this group are similar to those of groundwater from the drift, the wells in Unit D producing this type of water are completed at from 27 to 39 m depth. Therefore, it is unlikely that this is water that originated in the drift and moved into bedrock at shallow depth. Nor is it likely that this water represents drilling water remaining from the well installation process. The surface water in the Highvale area is generally 200 to 400 mg/L TDS, with a cation composition of approximately 20% higher sodium and magnesium than the groundwater in Unit D. It appears that this group of samples reflects the mineralogical composition within the siltstone of Unit D that gives rise to such an atypical groundwater chemistry. Alternatively, this group may represent high permeability zones within the siltstone of Unit D that are capable of transmitting shallow groundwater from the drift to relatively great depths, with a minimum of change in the chemical composition of the water.

The second compositional group of samples from Unit D is characterized by sodium-bicarbonate or sodium-bicarbonate-sulfate water with from 1500 to 1600 mg/L TDS. This group is typical of shallow bedrock aquifers in the Highvale area, but too few data are available from Unit D to generalize as to the lateral distribution of this group.

In the predominantly shale strata that form Unit C, the chemical makeup of the groundwater is sodium-bicarbonate, with from 5 to 20% sulfate (Figure 12). The TDS range from 1000 to 1750 mg/L (Figure 13). Sodium concentrations are generally around 300 mg/L, but range from 275 to 475 mg/L. Bicarbonate concentrations span a broader range, from 650 to 1200 mg/L (Figure 13). The samples with the highest bicarbonate concentrations also have the highest salinity.

Groundwater from the sandstone of Unit B covers a range of chemical compositions from sodium-bicarbonate to sodium-bicarbonate-sulfate (Figure 14). The sulfate component is generally 18 to 35% of the anion composition, although a significant number of samples (40%)

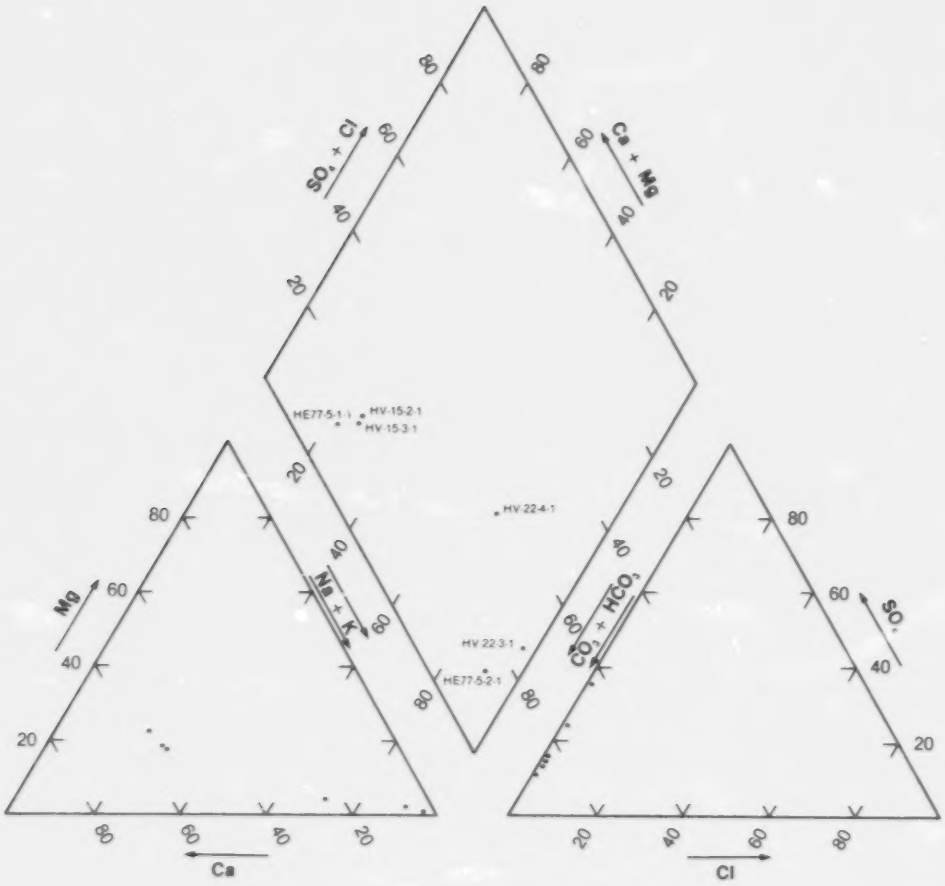

Figure 10. Piper trilinear diagram for groundwater samples from Unit D of the bedrock overburden.

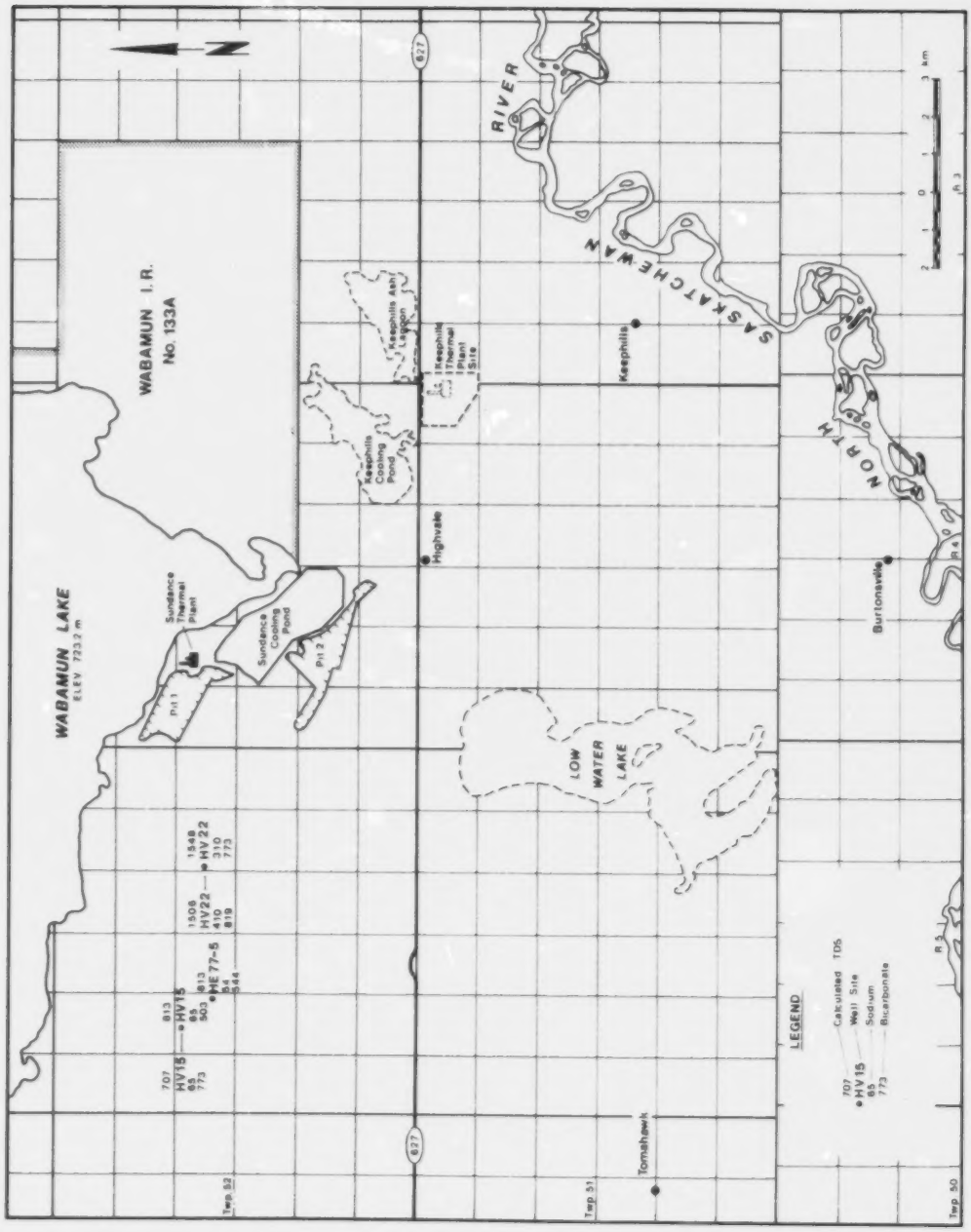

Figure 11. Concentration of total dissolved solids, sodium and bicarbonate in groundwater from Unit D of the bedrock overburden.

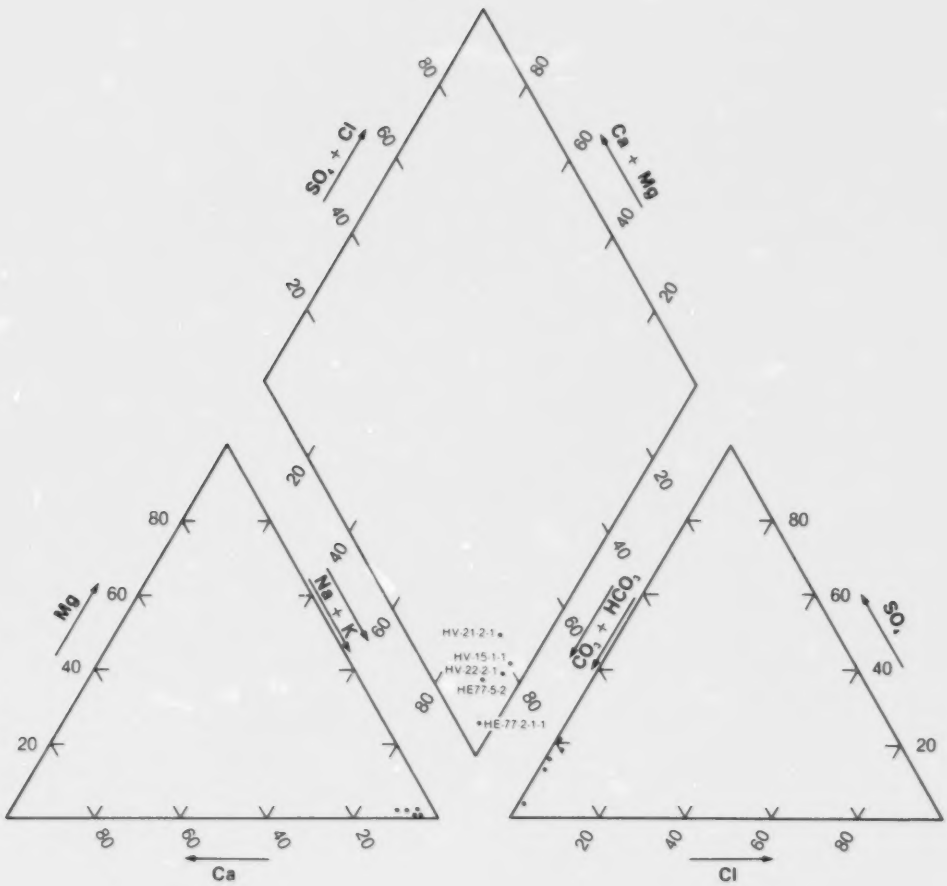

Figure 12. Piper trilinear diagram for groundwater samples from Unit C of the bedrock overburden.

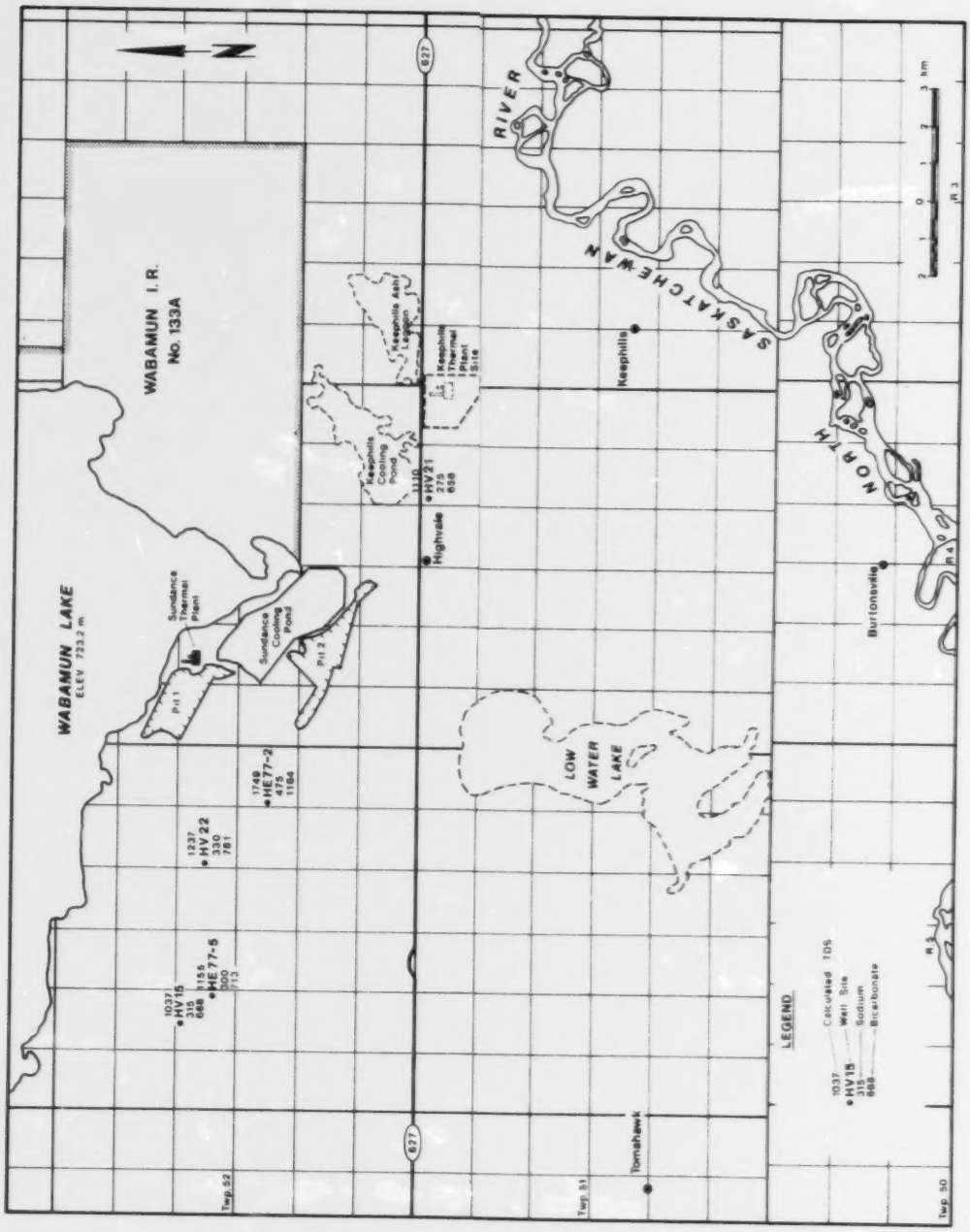

Figure 13. Concentration of total dissolved solids, sodium and bicarbonate in groundwater, from Unit C of the bedrock overburden.

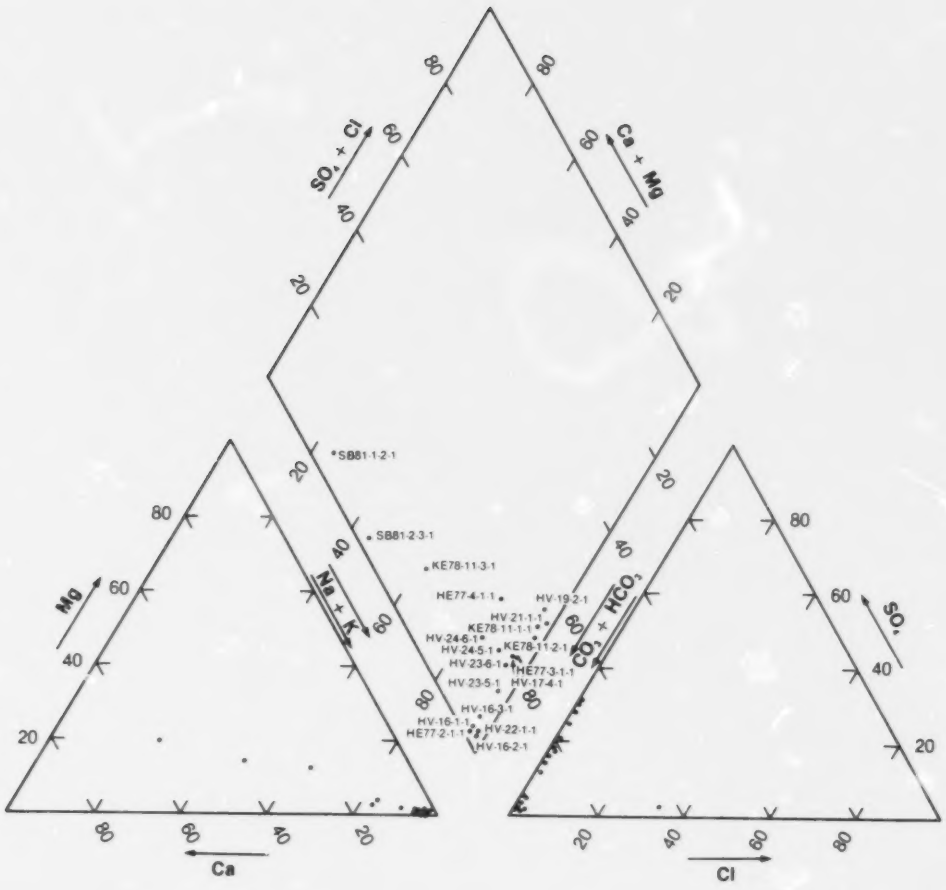

Figure 14. Piper trilinear diagram for groundwater samples from Unit B of the bedrock overburden (sandstone).

contain less than 10% sulfate. In 15% of the samples, calcium and magnesium are major cationic components, at 35 to 75% of the cations. The samples in this group also are of low salinity (600 to 1200 mg/L TDS) and are from sites located close to the subcrop of the sandstone of Unit B. These samples probably reflect shallow, local groundwater-flow systems with recharge from overlying drift, as opposed to the more regional bedrock flow system represented by the area south and west of the subcrop. In general, sodium concentrations in the sandstone of Unit B are in the range of 400 to 600 mg/L, and bicarbonate concentrations are from 600 to 1500 mg/L (Figure 15). The TDS concentrations range from 1200 to 2300 mg/L over most of the site (Figure 15), except very close to the subcrop as previously noted.

Oxygen-18 values for groundwater from the bedrock overburden range from -17 to -20 per mille, and deuterium values range from -135 to -157 per mille. On a plot of deuterium vs oxygen-18 (Figure 16) the points cluster around the meteoric water line, indicating that the source of recharge is precipitation, more specifically snowmelt and early spring rainfall.

Because of the small number of samples from the overburden Units C and D, the gypsum saturation and ion exchange characteristics for the entire bedrock overburden are described. In addition, characteristics of the sandstone of Unit B are summarized independently, since in many instances where the cover over the coal is relatively thin this horizon makes up most or all of the bedrock overburden.

Groundwater in the bedrock overburden is in all cases undersaturated with gypsum, a characteristic that reflects generally low concentrations of both calcium and sulfate. The mean saturation index value for gypsum in the groundwater in the bedrock overburden is -2.511 (standard deviation = 0.872, n = 16) with a range of -4.60 to 1.22. Within the sandstone of Unit B alone, the mean gypsum SI value is -2.602 (standard deviation = 0.928, n = 12) with a range of values from -4.60 to -1.22.

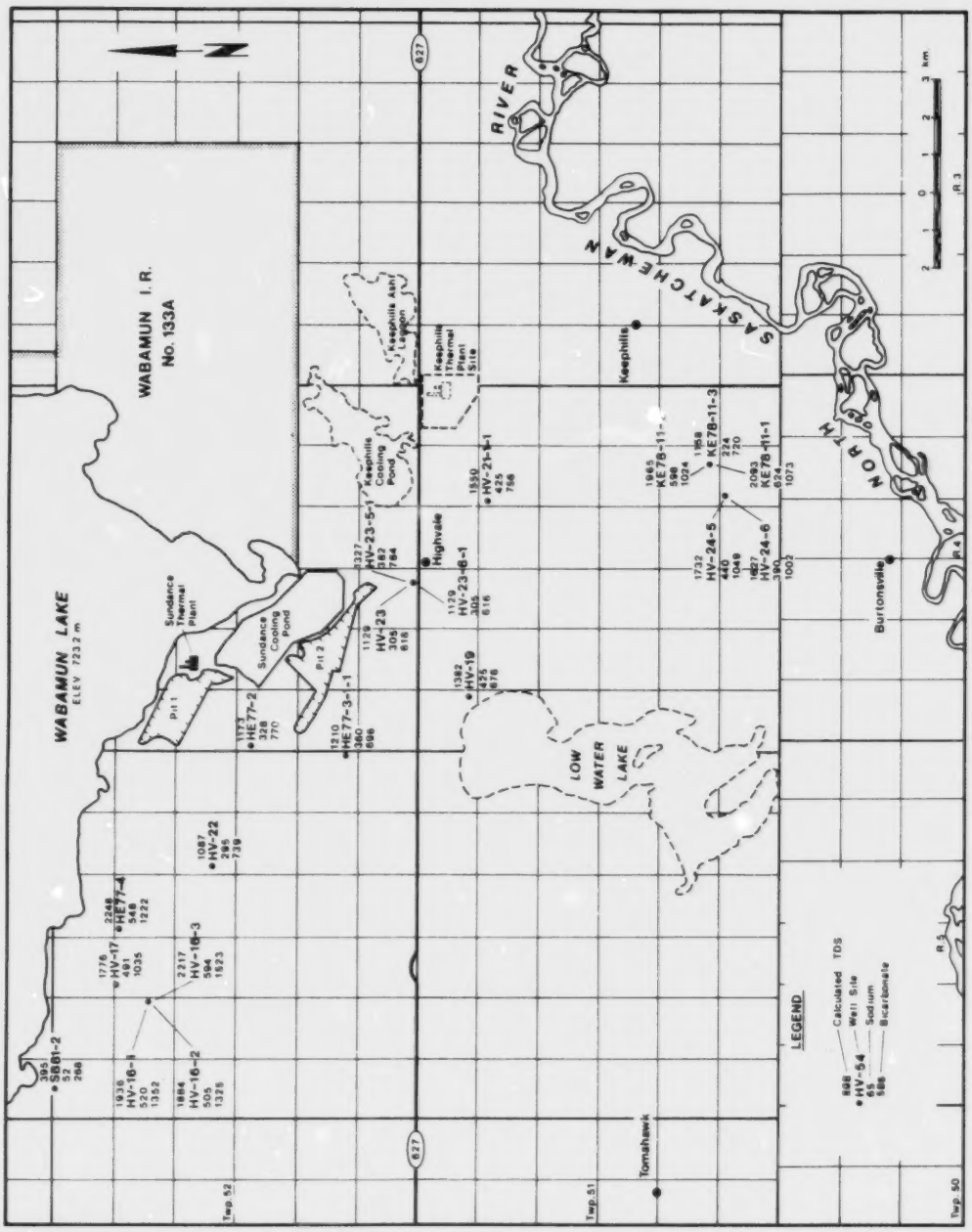

Figure 15. Concentration of total dissolved solids, sodium and bicarbonate in groundwater from Unit B of the bedrock overburden (sandstone).

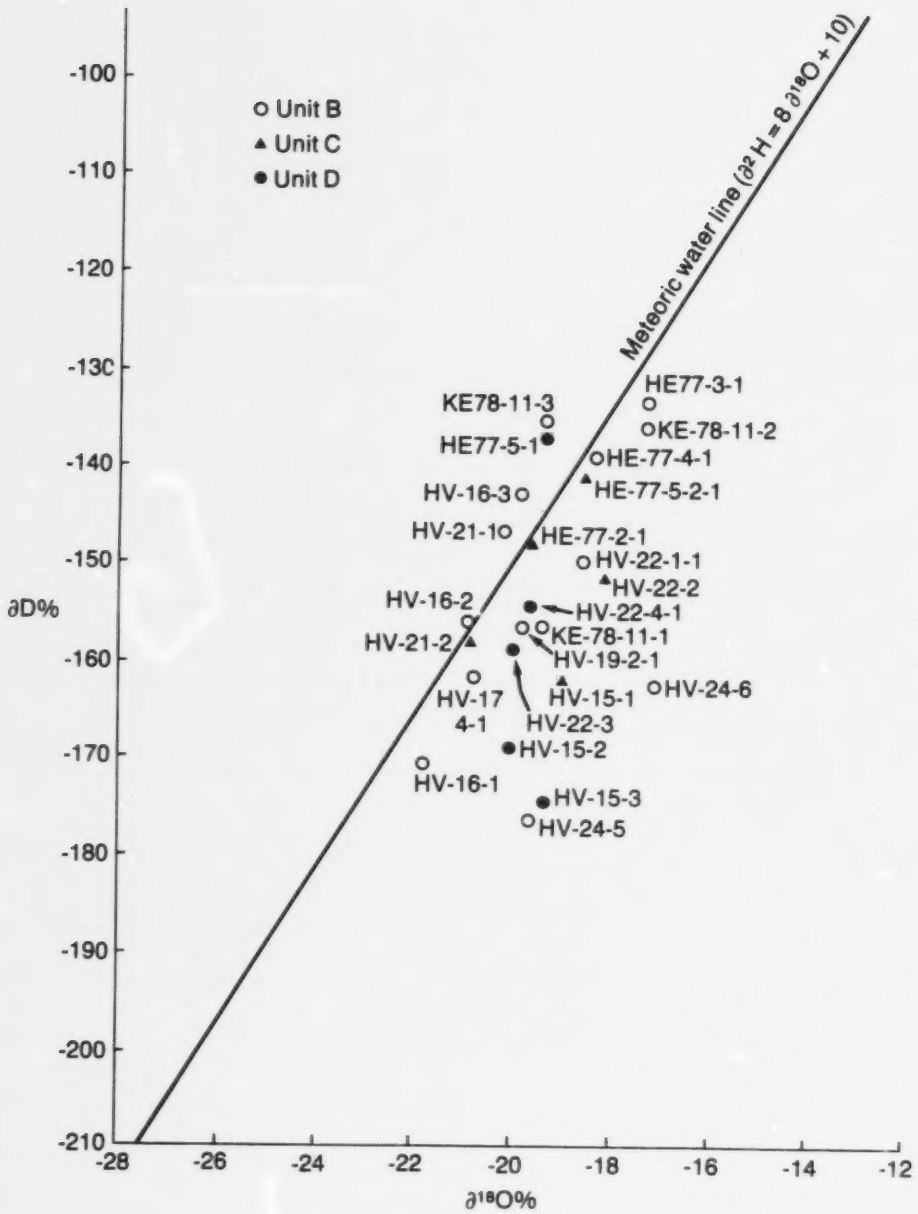

Figure 16. Deuterium versus oxygen-18 for groundwater samples from the bedrock overburden.

The modified selectivity coefficient (K') values of the bedrock overburden reflect the mineralogical makeup of the rock, particularly the montmorillonite content, which averages 40 to 70% of the clay fraction of the bedrock in the overburden (Maslowski Schutze in press). The mean K' value for bedrock overburden is 2.616 (standard deviation = 3.196, n = 16), with individual K' values ranging from 1.9×10^{-3} to 13.10. Within the sandstone of Unit B the mean K' value is 3.323 (standard deviation = 3.390, n = 12), with the same range of values as the bedrock overburden as a whole.

4.3 THE ARDLEY COAL ZONE

Three of the six seams of the Ardley Coal Zone, Seams #1, #2, and #6, are thicker than the remaining seams and are reasonably well instrumented for groundwater monitoring. Coal Seams #3, #4, and #5, which are generally very thin, contain very limited instrumentation. Within the coal zone, indications are that in most cases the individual seams are hydraulically connected. At eight of 12 sites studied in which more than one seam was instrumented, the water levels in both shallow and deep coal seams were essentially the same. At four of the 12 sites, on the other hand, significant vertical gradients were observed, with head losses between 2.6 and 9.7 m across the approximately 15 m thick zone. This suggests that the partings within the coal in some places act as a significant impediment to groundwater movement between seams, although this is not generally the case.

4.3.1 Coal Seam #1

In the part of the study area south of Lake Wabamun, the groundwater flow in Coal Seam #1, as illustrated by the piezometric surface map (Figure 17), is primarily to the north and northeast, from the east-west trending escarpment toward Lake Wabamun. There is an east-west trending divide through the Low Water Lake area, separating flow into a northern component toward Lake Wabamun, the Highvale Mine excavations and the coal subcrop, and a southern

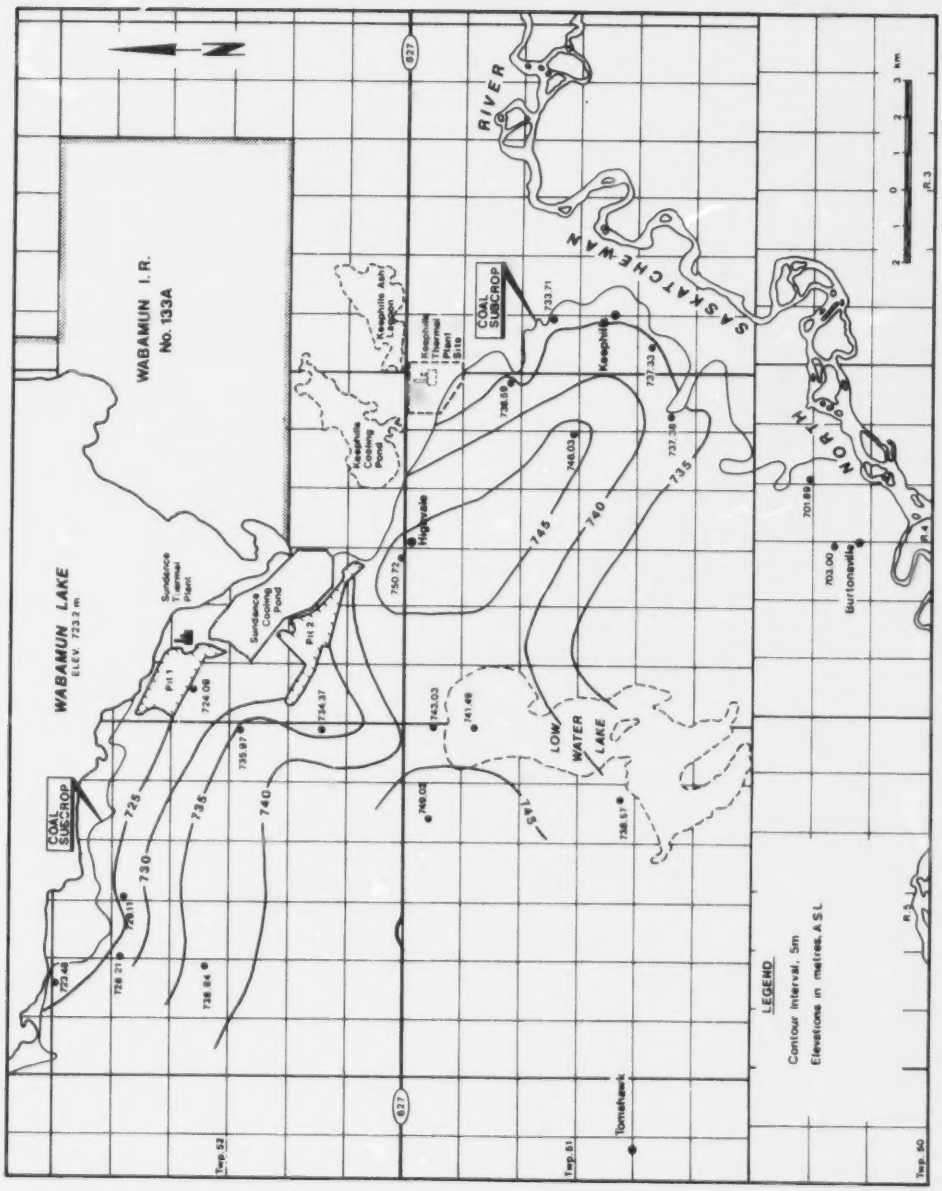

Figure 17. Piezometric surface map for Coal Seam #1.

component flowing south or southeast toward the coal subcrop and the North Saskatchewan River.

The chemical makeup of groundwater is variable, but most samples are of Na^+ - HCO_3^- type, with TDS concentrations ranging from 1300 to 1900 mg/L (Figures 18 and 19). Calcium, sodium-bicarbonate water with low TDS (800 to 1300 mg/L) occurs in some places, and calcium-bicarbonate, sufate water with relatively high TDS (1900 mg/L) was detected at one site (HE77-4) (Figures 18 and 19). Sodium concentrations in Coal Seam #1 are typically 400 to 500 mg/L and bicarbonate concentrations generally range between 800 to 1200 mg/L (Figure 19).

A plot of deuterium vs oxygen-18 for four groundwater samples from Coal Seam #1 (Figure 20) indicates that the source of recharge is primarily meteoric in origin, and is dominated by snowmelt and early spring recharge. One sample, HE77-5-3-1, has a somewhat evaporitic character and is slightly heavier isotopically than the other three samples, and may reflect a mixing of residual drilling water with the groundwater.

The gypsum saturation index values from Coal Seam #1 range from -3.91 to -1.25, with a mean SI value of -2.439 (standard deviation = 0.837, n = 7). These values are comparable to gypsum SI values in the overlying bedrock, although the coal tends to have somewhat higher calcium concentrations and slightly lower sulfate concentrations. The relatively high calcium concentrations in Coal Seam #1 probably reflects the concentration of the available instrumentation relatively close to the coal subcrop, where calcareous drift materials are separated from the coal only by thin bedrock overburden.

The slightly higher calcium concentrations in Coal Seam #1 are also reflected in the modified selectivity coefficient (K') values for this unit. The mean K' for Coal Seam #1 is 1.097, with a range from 0.017 to 2.55, and a standard deviation of 1.016 (n = 7). This mean K' is only about one-third of the mean value for the overlying sandstone of Unit B, and results from higher calcium

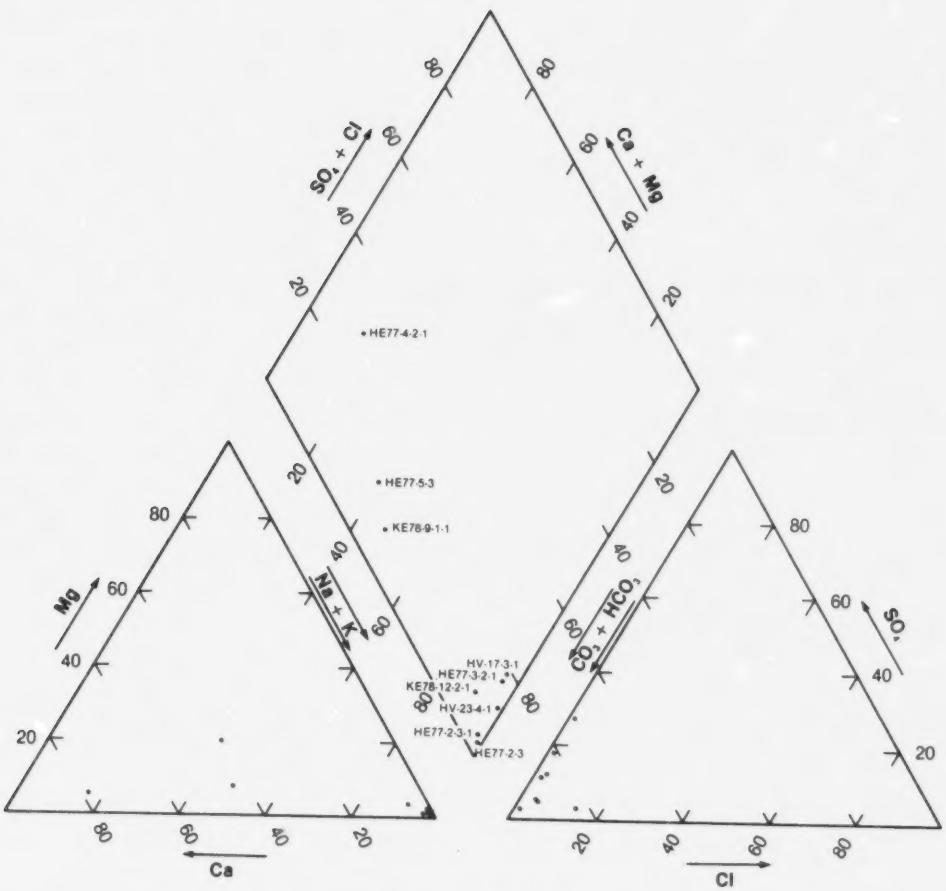

Figure 18. Piper trilinear diagram for groundwater samples from Coal Seam #1.

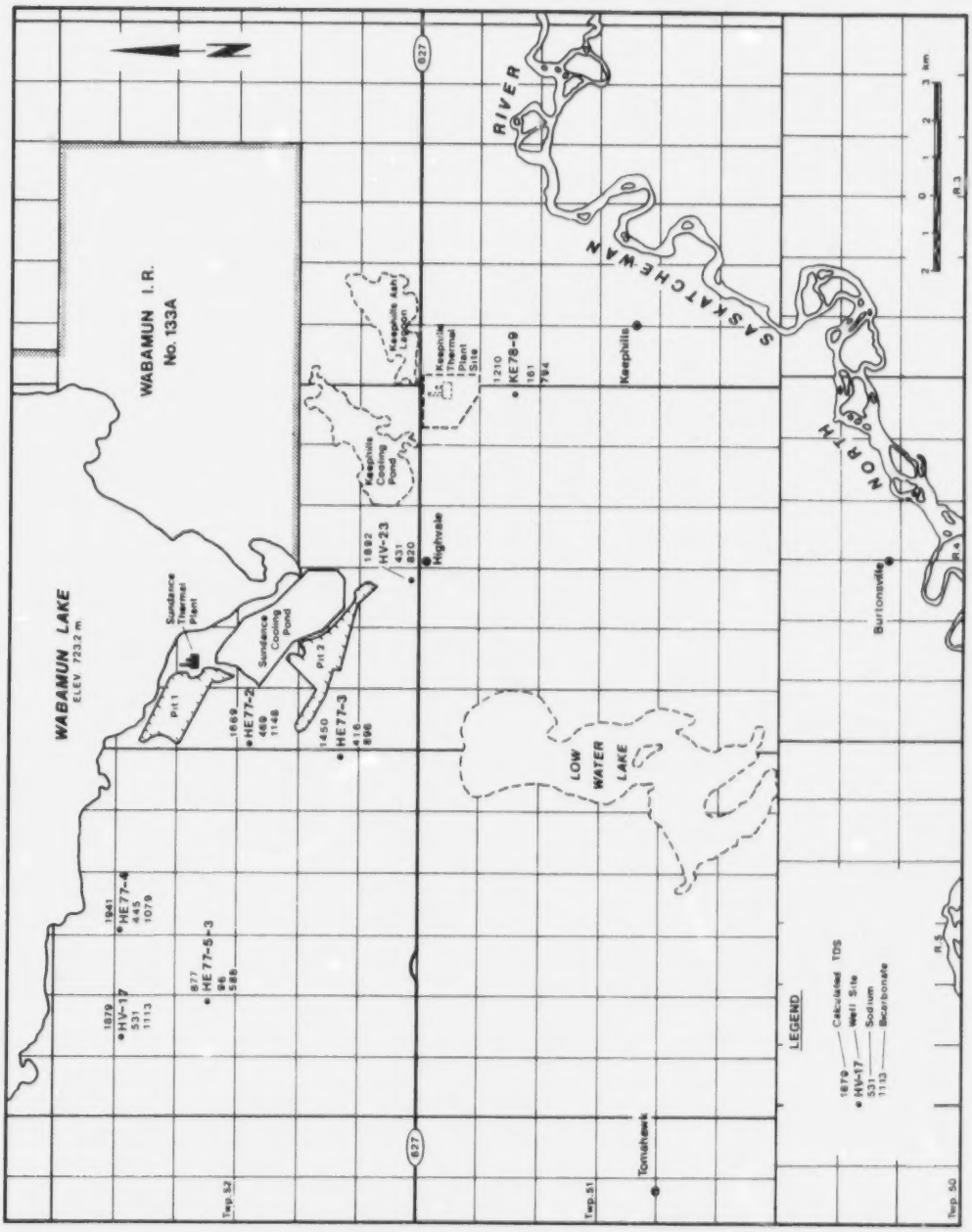

Figure 19. Concentration of total dissolved solids, sodium and bicarbonate in groundwater from Coal Seam #1.

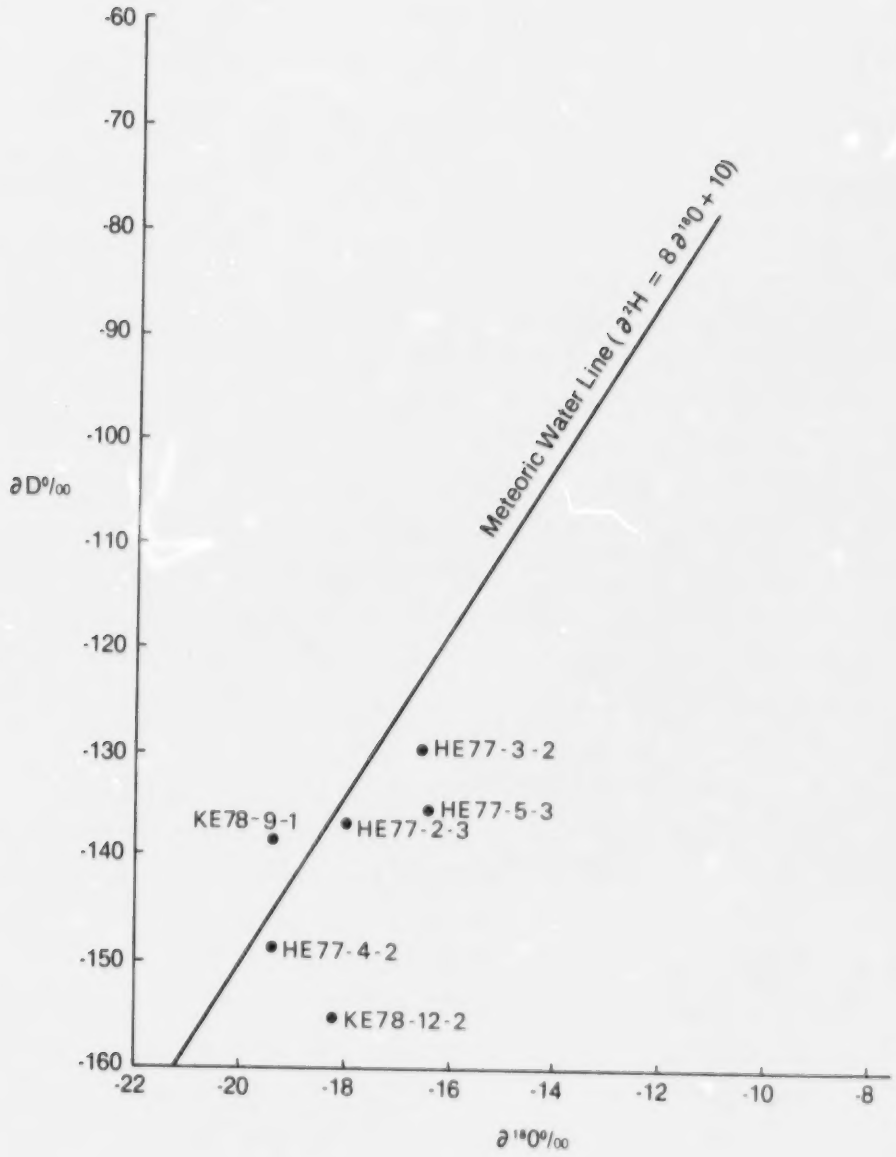

Figure 20. Deuterium versus oxygen-18 for groundwater samples from Coal Seam #1.

concentrations in the coal than the sandstone. In addition, the coal does not have the high montmorillonitic clay content of the overburden sandstone, and therefore does not have the same potential to shape the chemical composition of the groundwater in situ by ion exchange, relying, instead, on the groundwater characteristics inherited from overlying strata.

4.3.2 Coal Seam #2

The groundwater-flow pattern in Coal Seam #2 is essentially the same as that described for Coal Seam #1, with minor apparent differences probably due to differences in the distribution of data points. The major groundwater-flow features in Coal Seam #2 are an east-west trending divide through Low Water Lake, and a potentiometric high in the area south of the Hamlet of Highvale that extends west toward Low Water Lake (Figure 21). On the south side of Lake Wabamun, groundwater flow is from south to north, corresponding to the regional topographic slope.

In the eastern part of the study area, groundwater flow is strongly eastward, toward the subcrop of the coal. South of the regional divide through Low Water Lake, groundwater flow is to the south toward the coal subcrop and the North Saskatchewan River. The relatively high hydraulic heads in the vicinity of Low Water Lake indicate that it is a source of groundwater recharge to the coal zone. This relationship is most noticeable on the piezometric surface map for Coal Seam #2, for which the most data are available.

The chemical makeup of groundwater from Coal Seam #2 is very similar to that of Coal Seam #1, although somewhat more saline. The groundwater in Coal Seam #2 is primarily of sodium-bicarbonate type, with TDS ranging from 1500 to 2500 mg/L (Figures 22 and 23). As in the shallower coal, a minor group of samples have a significant calcium component, and the resulting sodium, calcium-bicarbonate water is of lower salinity (1100 to 1500 mg/L TDS) than the higher sodium water. Sodium concentrations in Coal Seam #2 are typically from 400 to 700 mg/L, and bicarbonate concentrations generally from

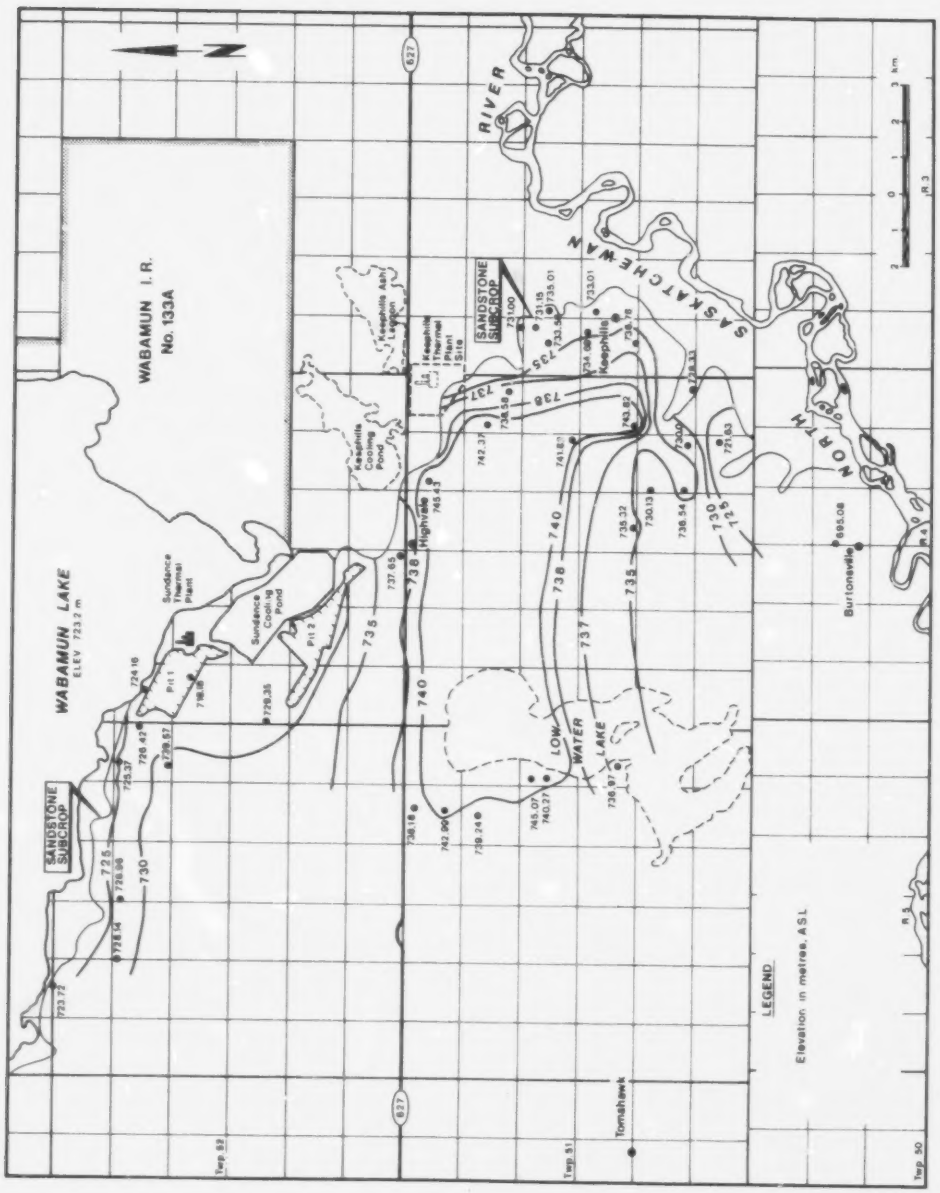

Figure 21. Piezometric surface map for Coal Seam #2.

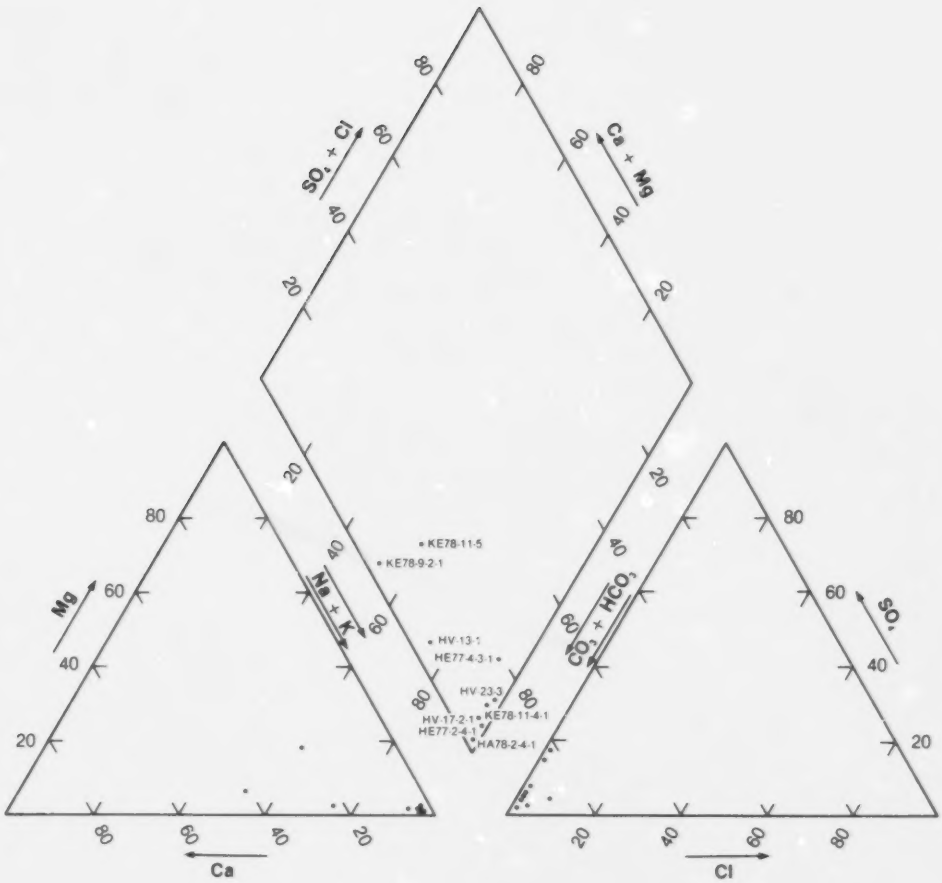

Figure 22. Piper trilinear diagram for groundwater samples from Coal Seam #2.

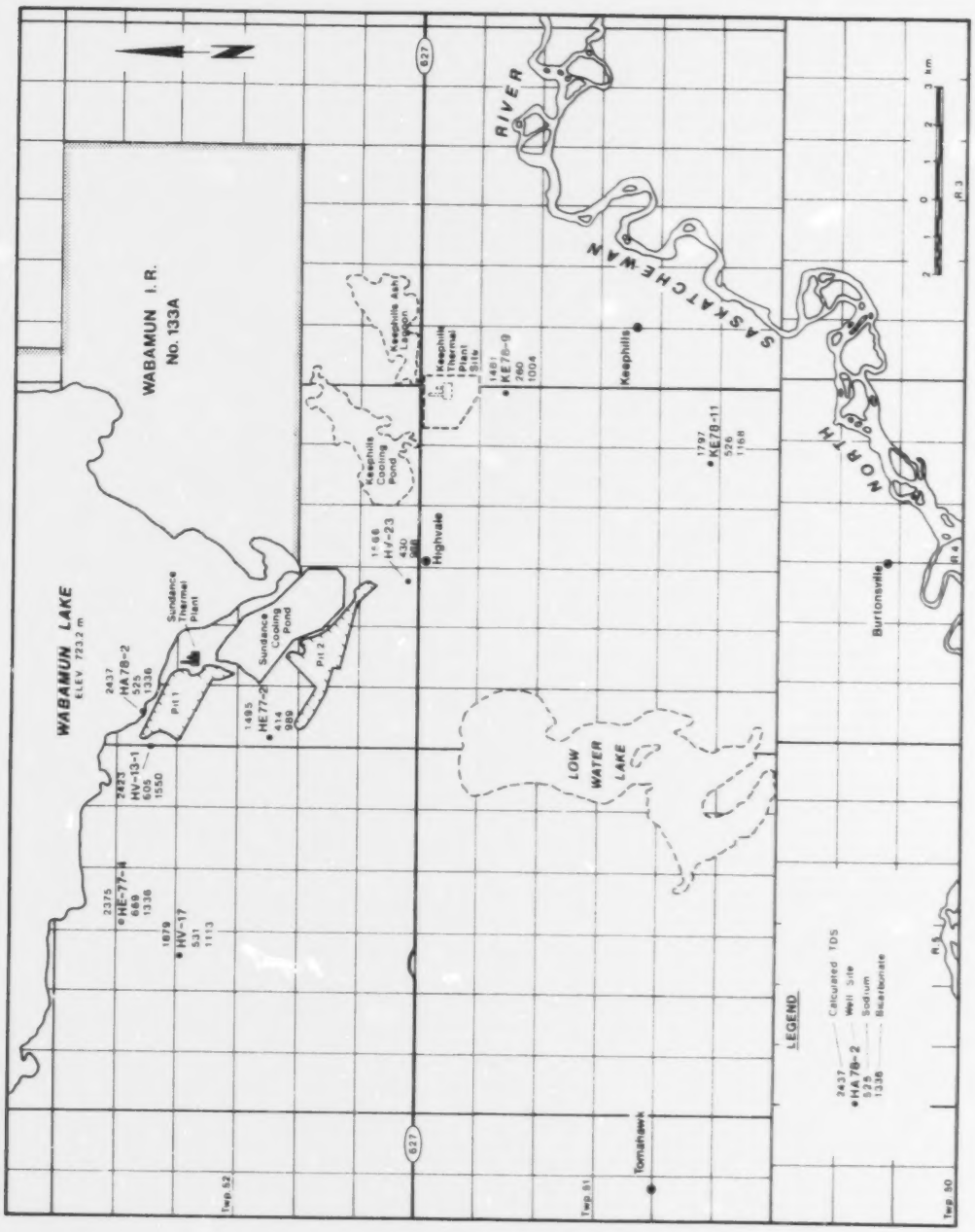

Figure 23. Concentration of total dissolved solids, sodium and bicarbonate in groundwater from Coal Seam #2.

1000 to 1300 mg/L (Figure 23). Sulfate is generally less than 60 mg/L, except in the northwest part of the study area where sulfate concentrations are approximately 200 mg/L.

In Coal Seam #2 the groundwater has calcium concentrations that, as in Coal Seam #1, are somewhat higher than those from the groundwater in the overburden bedrock, and also sulfate concentrations that are lower than the water in the overburden, resulting in a mean gypsum SI that is in fact very similar to that from the sandstone of Unit B. The mean gypsum SI in groundwater from Coal Seam #2 is -2.589 (compared to -2.602 in Unit B) with a standard deviation of 0.734 (n = 7). Individual SI values range from -3.96 to -1.63. The gypsum saturation characteristics of Coal Seam #2 are intermediate between those of Coal Seam #1 and the bedrock overburden sandstone, Unit B.

Stable isotope data for groundwater from Coal Seam #2 indicate that recharge to this coal seam is of meteoric origin, as shown in Figure 24. Oxygen-18 and deuterium values plot along the meteoric-water line, with a range of values that indicates that most of the groundwater recharge is from snowmelt or early spring rains.

The ion exchange characteristics of Coal Seam #2, on the other hand, are much more like those in Coal Seam #1 than the bedrock overburden. This is due to the relatively high calcium concentrations in Coal Seam #2, which, as in Coal Seam #1, result in lower K' values. The mean modified selectivity coefficient (K') for Coal Seam #2 is 1.796, with a standard deviation of 1.274 (n = 7) and with individual values ranging from 6.8×10^{-6} to 3.32.

4.3.3 Coal Seam #6

The groundwater-flow pattern in Coal Seam #6 is very similar to that in Coal Seams #1 and #2. Flow is mainly from south to north, downslope, toward Lake Wabamun (Figure 25). A potentiometric high is situated in the southeast part of the study area, with components of flow eastward toward the coal subcrop and southward toward the North Saskatchewan River valley. There is too

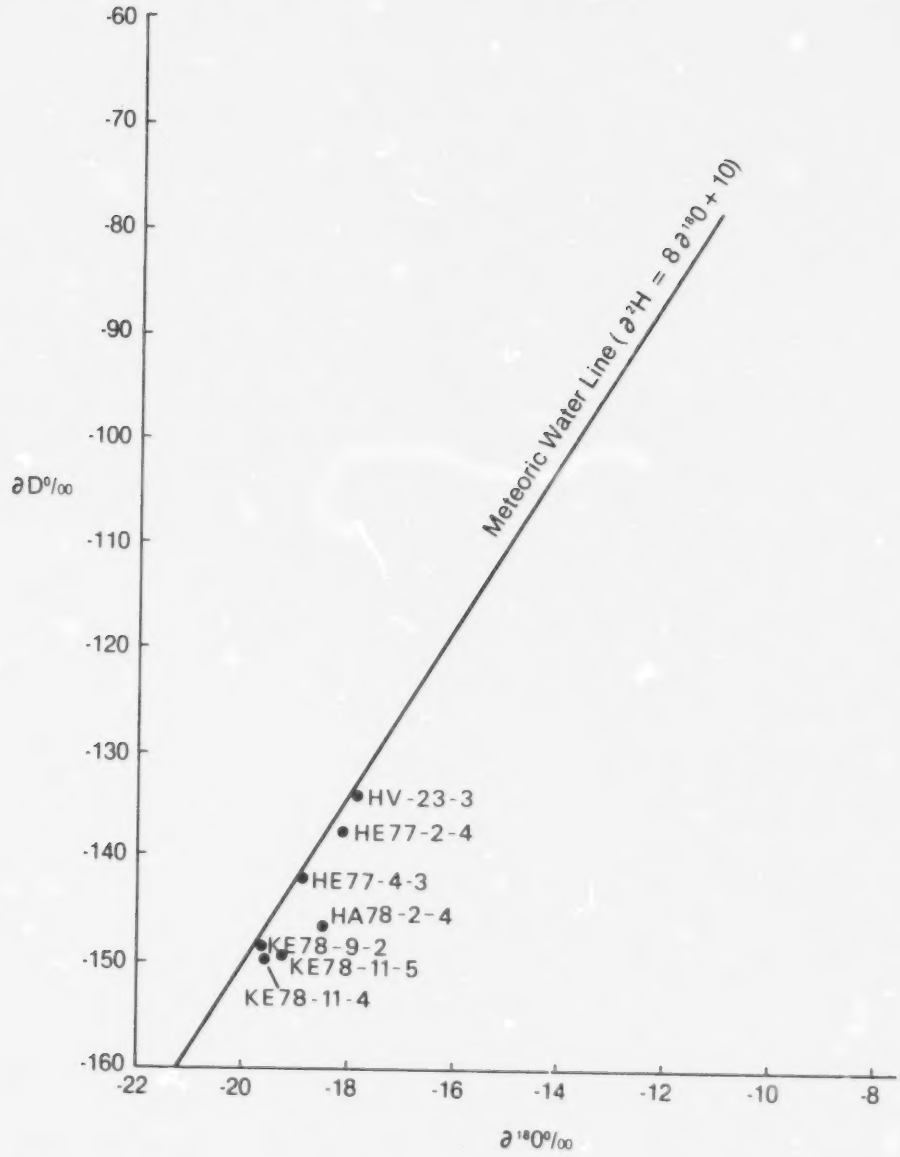

Figure 24. Deuterium versus oxygen-18 for groundwater samples from Coal Seam #2.

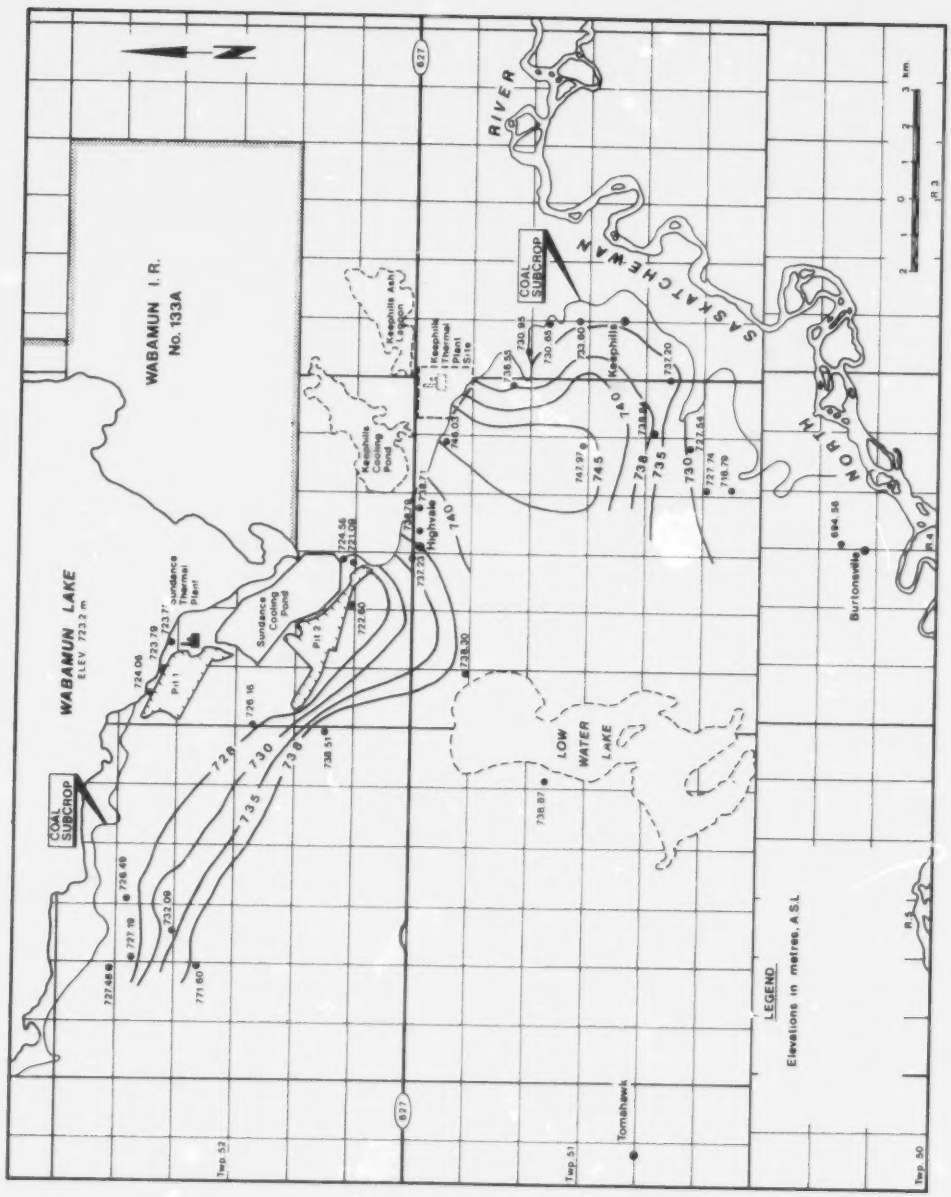

Figure 25. Piezometric surface map for Coal Seam #6.

little instrumentation in the Low Water Lake basin to evaluate the groundwater-flow system in Coal Seam #6 for this area, but in all likelihood the regional east-west groundwater divide observed in the shallower coal seams is also present in Coal Seam #6. The hydraulic head in Coal Seam #6 is everywhere higher than the level of Lake Wabamun (Figure 25) indicating that there is the potential for groundwater discharge from the coal zone to the lake.

Stable isotope data for Coal Seam #6 (Figure 26) indicate that snowmelt and early spring rainfall are the principal sources of recharge water. Oxygen-18 and deuterium values cluster around -18.5 and -142 per mille, respectively, and plot close to the meteoric water line. One sample of groundwater from Coal Seam #6, from Site HA78-6, has an isotopic composition that is much heavier than the other samples, and plots well to the right of the meteoric water line in Figure 26. This indicates that the groundwater in Coal Seam #6 at that site is from an evaporitic source, that is, a surface water pond. In fact, the isotopic composition of the sample from Site HA78-6 is typical of that in pond water in the Highvale area. The location of Site HA78-6 immediately adjacent to the Sundance Cooling Pond, and between the pond and Pit 02 of the Highvale Mine, indicates that cooling pond water is leaking into the coal seam and probably discharging into Pit 02. This interpretation is consistent with observations of groundwater discharge from the coal zone along the north Highwall face in the east end of Pit 02.

Sodium and bicarbonate are the principal ionic components of the groundwater from Coal Seam #6, with TDS ranging from 700 to 2800 mg/L (Figures 27 and 28). Sodium concentrations are typically from 400 to 600 mg/L, and bicarbonate from 900 to 1200 mg/L (Figure 28). Unlike Coal Seams #1 and #2, sulfate concentrations in Coal Seam #6 are highest in the southeast part of the study area (at 100 to 300 mg/L) and lowest (less than 50 mg/L) in the area south of Lake Wabamun.

In Coal Seam #6 the gypsum saturation and ion exchange characteristics are unlike those of either the overlying coal seams

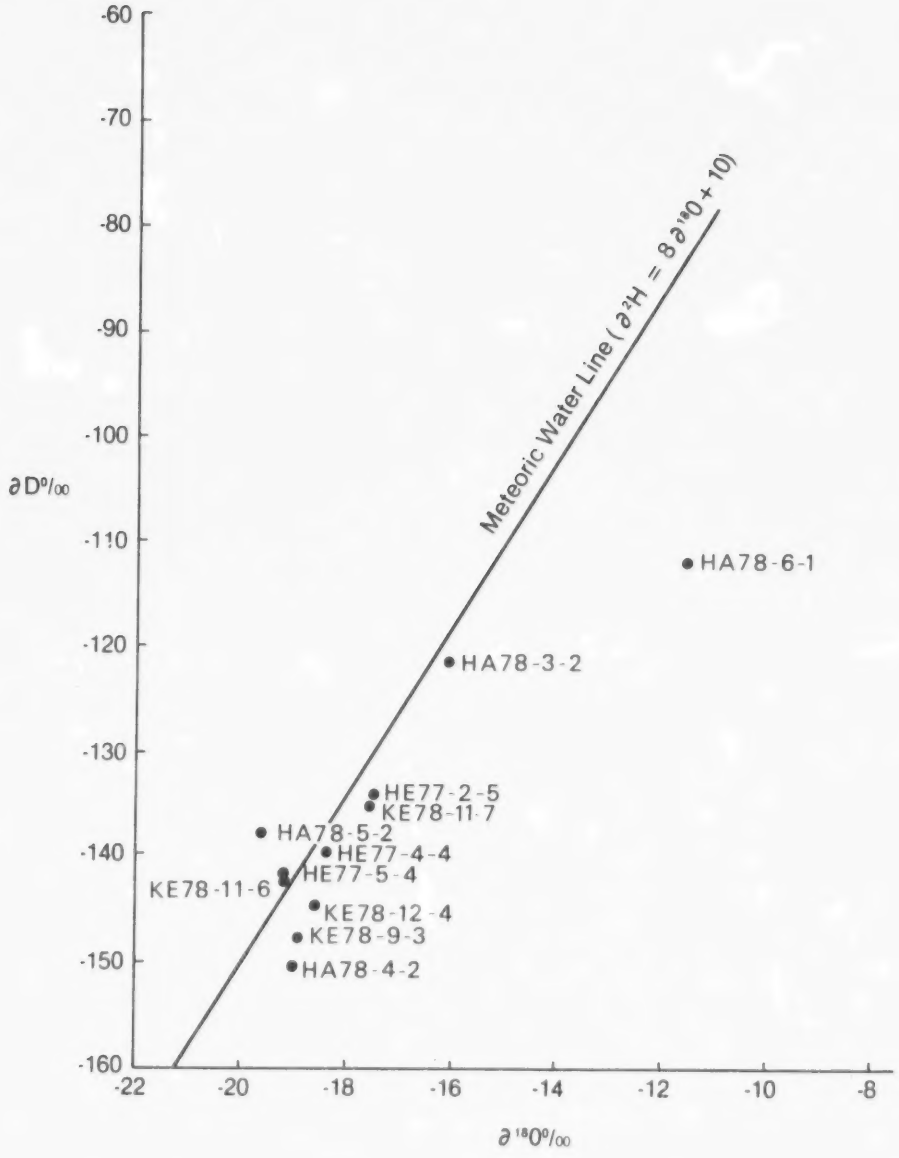

Figure 26. Deuterium vs oxygen-18 for groundwater samples from Coal Seam #6.

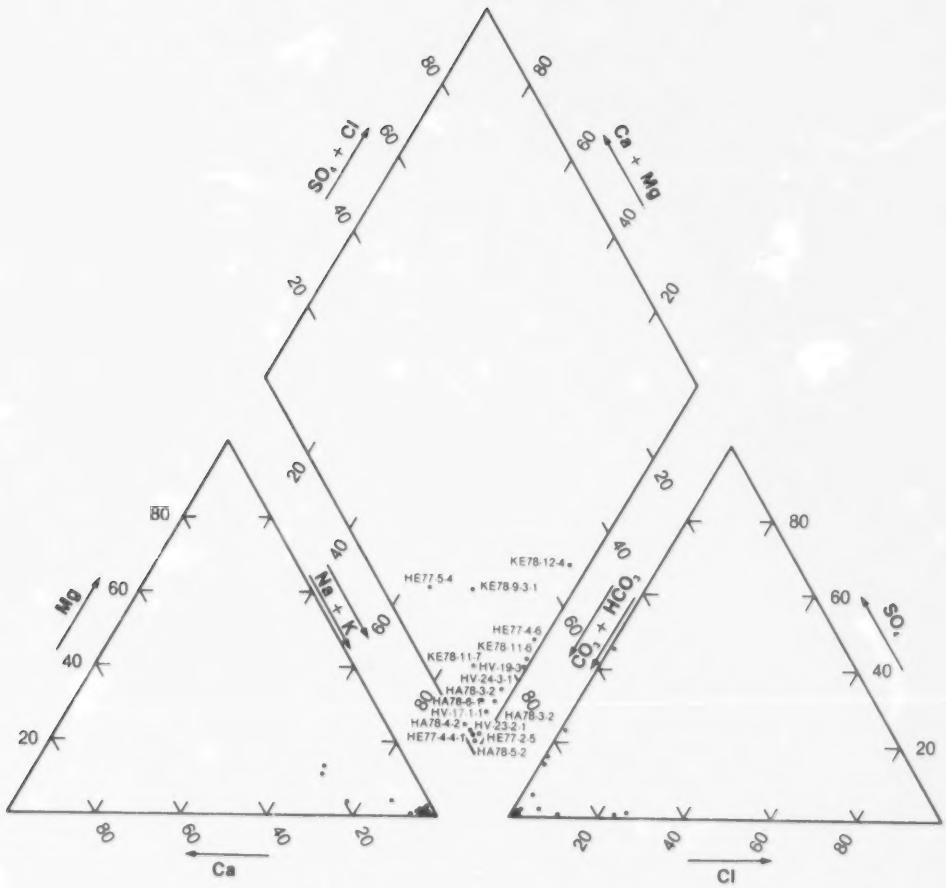

Figure 27. Piper trilinear diagram for groundwater samples from Coal Seam #6.

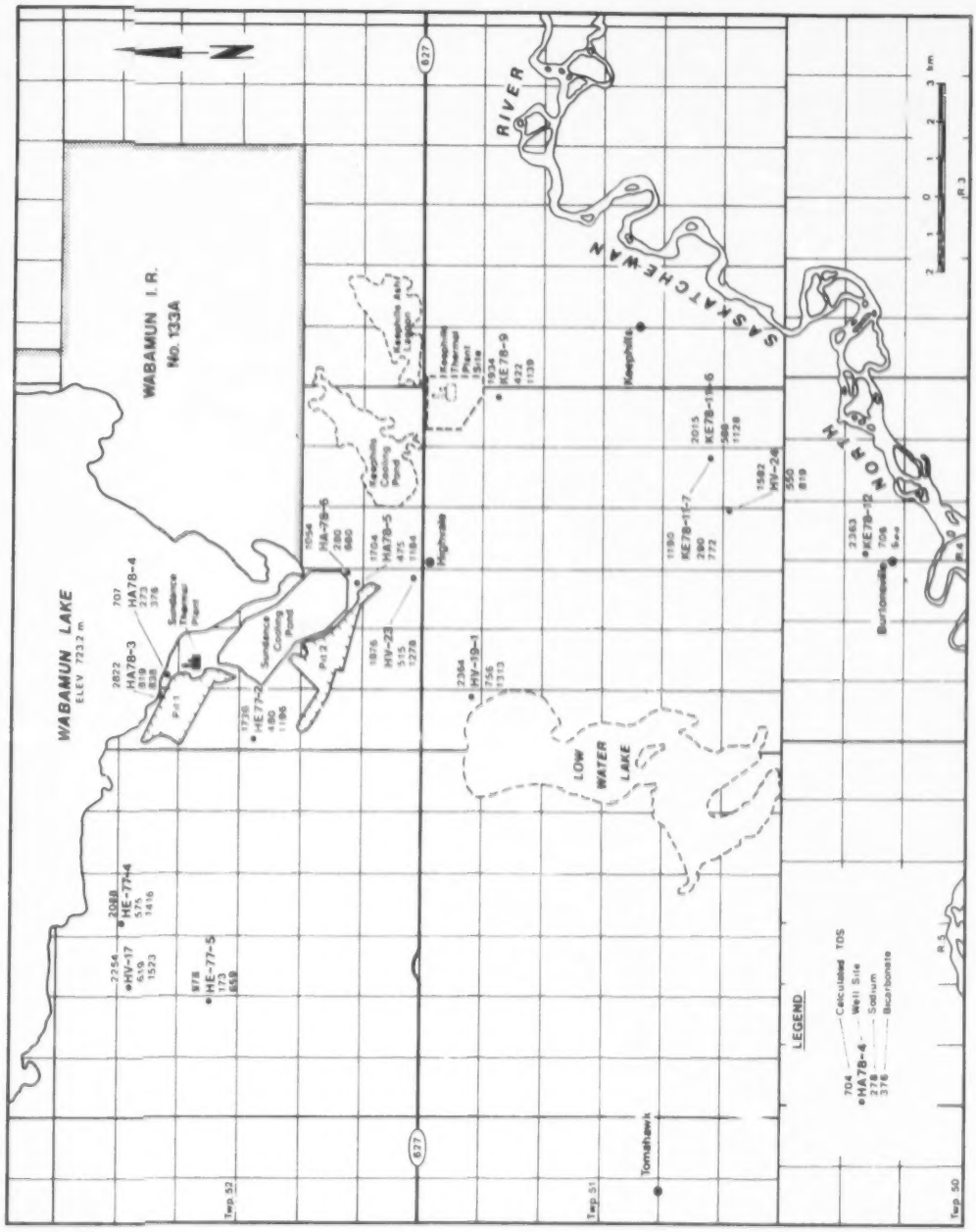

Figure 28. Concentration of total dissolved solids, sodium and bicarbonate in groundwater from Coal Seam #6.

or the bedrock overburden. It is likely that these properties within Coal Seam #6 are influenced by the numerous shale partings that separate Coal Seam #6 from the upper seams. The mean gypsum saturation index for groundwater from Coal Seam #6 is -3.175 (standard deviation = 1.119, n = 11), with individual values ranging from -4.49 to -1.30. The mean modified selectivity coefficient (K') from groundwater from Coal Seam #6 is 3.197 (standard deviation = 2.548, n = 11), reflecting a combination of both higher sodium concentrations and lower calcium concentrations in Coal Seam #6, relative to Coal Seams #1 and #2. Individual K' values in Coal Seam #6 range from 0.225 to 8.942.

4.4 SANDSTONE OF THE SCOLLARD MEMBER BELOW THE ARDLEY COAL ZONE

A relatively large number of piezometers have been completed in the sandstone horizon of the Scollard Member that is situated immediately below the Ardley Coal Zone. The groundwater-flow pattern in this unit is primarily to the north or northwest in the area south of Lake Wabamun (Figure 29). In the east part of the study area, a potentiometric mound is present near the Keephills Cooling Pond and Keephills Plant Site, with flow directed to the southwest and south, downdip from the sandstone subcrop. The source of recharge supporting this mound appears to be the numerous ponds in the area north of the Keephills Plant Site, but there are insufficient stable isotope data available to evaluate this hypothesis. A second potentiometric mound is located south and west of the Village of Keephills, with flow directed to the northeast and to the northwest away from the mound.

Oxygen-18 and deuterium data available for this stratigraphic unit are very limited, with only three samples from restricted, atypical settings having been analysed; two of the sites are located down gradient from Pit 01 of the Highvale Mine, and the third is immediately adjacent to the Sundance Cooling Pond. Consequently, no conclusions can be reached regarding the source of

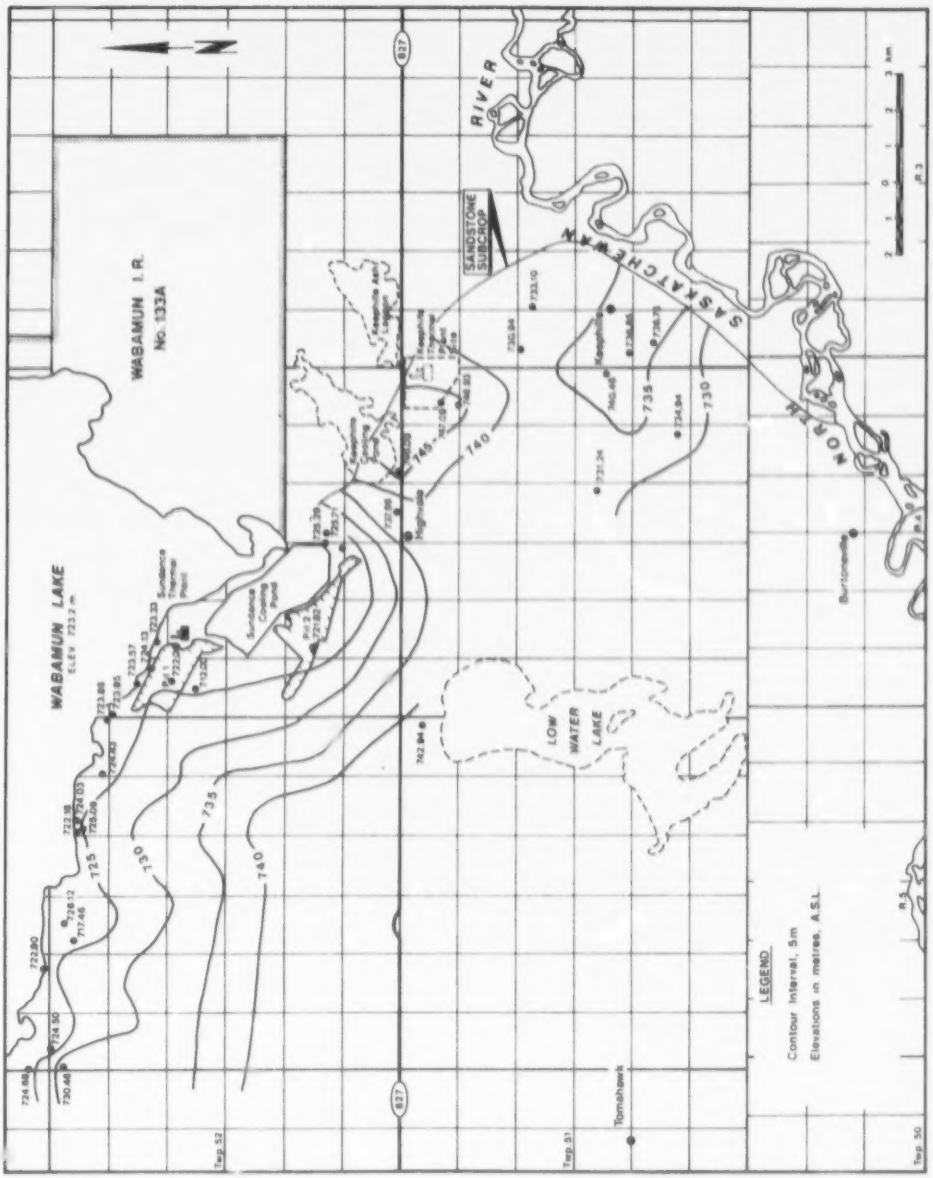

Figure 29. Piezometric surface map for the Scollard Member sandstone.

recharge for the sandstone of the Scollard Member on the basis of stable isotope data.

The chemical makeup of water from sandstone of the Scollard Member can be characterized only in general terms because of the small number and atypical distribution of samples. On the basis of four samples from sites in close proximity to Highvale Mine, the water quality in this sandstone unit is very similar to that in the overlying coal zone. Sodium and bicarbonate are the major ionic components, with TDS ranging from 1200 to 2400 mg/L (Figures 30 and 31). Sodium concentrations are from 300 to 700 mg/L and bicarbonate from 700 to 1600 mg/L (Figure 31).

Only two samples from sandstone of the Scollard Member have been analysed using the WATEQF model. From these two samples, gypsum saturation index values of -3.99 and -1.95 were determined for Sites HA78-4-1 and HE77-5-4, respectively. Similarly, the modified selectivity coefficients for these sites are 3.812 and 0.063, respectively.

4.5 SANDSTONE BEDS OF THE HORSESHOE CANYON FORMATION

The groundwater-flow system in sandstone of the Upper Horseshoe Canyon can only be documented in the eastern part of the Highvale study area, where there is adequate instrumentation. In the northeast part of the study area, where sandstone of the the Upper Horseshoe Canyon subcrops or lies under shallow cover, a potentiometric mound is present (Figure 32). Although this mound occurs in the vicinity of the Keephills Ash Lagoon, the lagoon was not used prior to 1983 and is not associated with the potentiometric mound. This mound drives the flow radially to the southwest and to the southeast, toward a discharge area along the valley of the North Saskatchewan River, and to the east-northwest toward the Wabamun Creek valley and valley scarp. From this mound there may also be a component of flow directed toward Lake Wabamun, although the very low hydraulic head in sandstone of the Upper Horseshoe Canyon in the area south of Lake Wabamun where it lies under thick cover suggests that

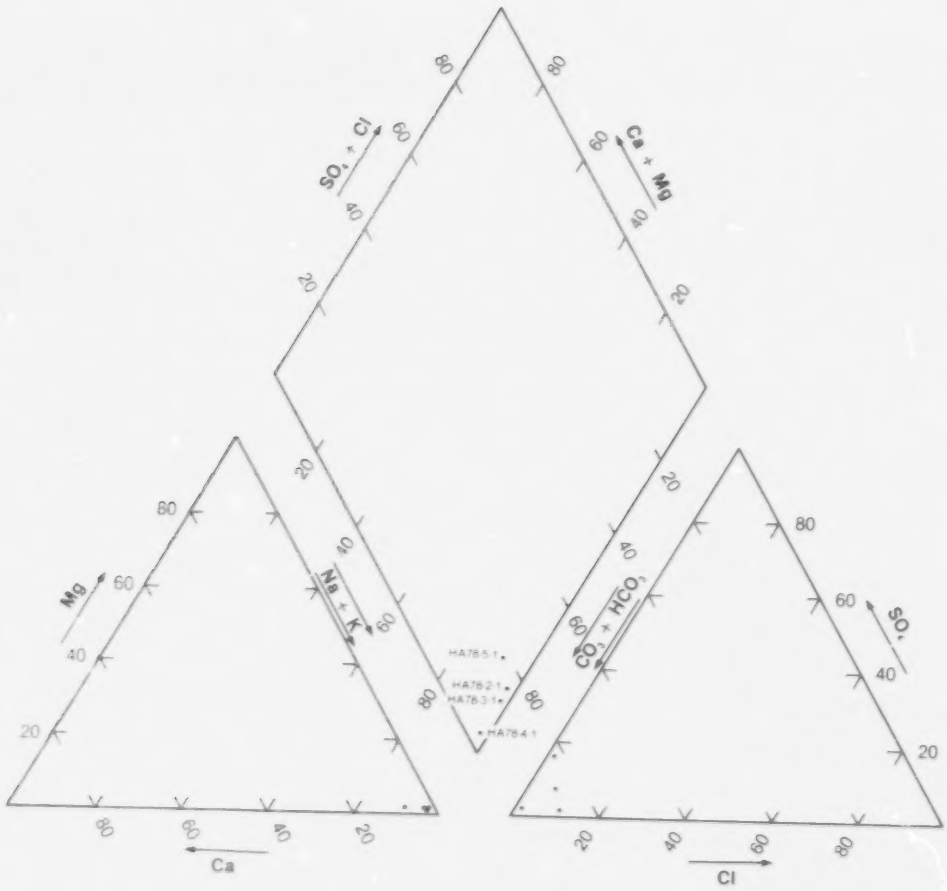

Figure 30. Piper trilinear diagram for groundwater samples from the Scollard Member Sandstone.

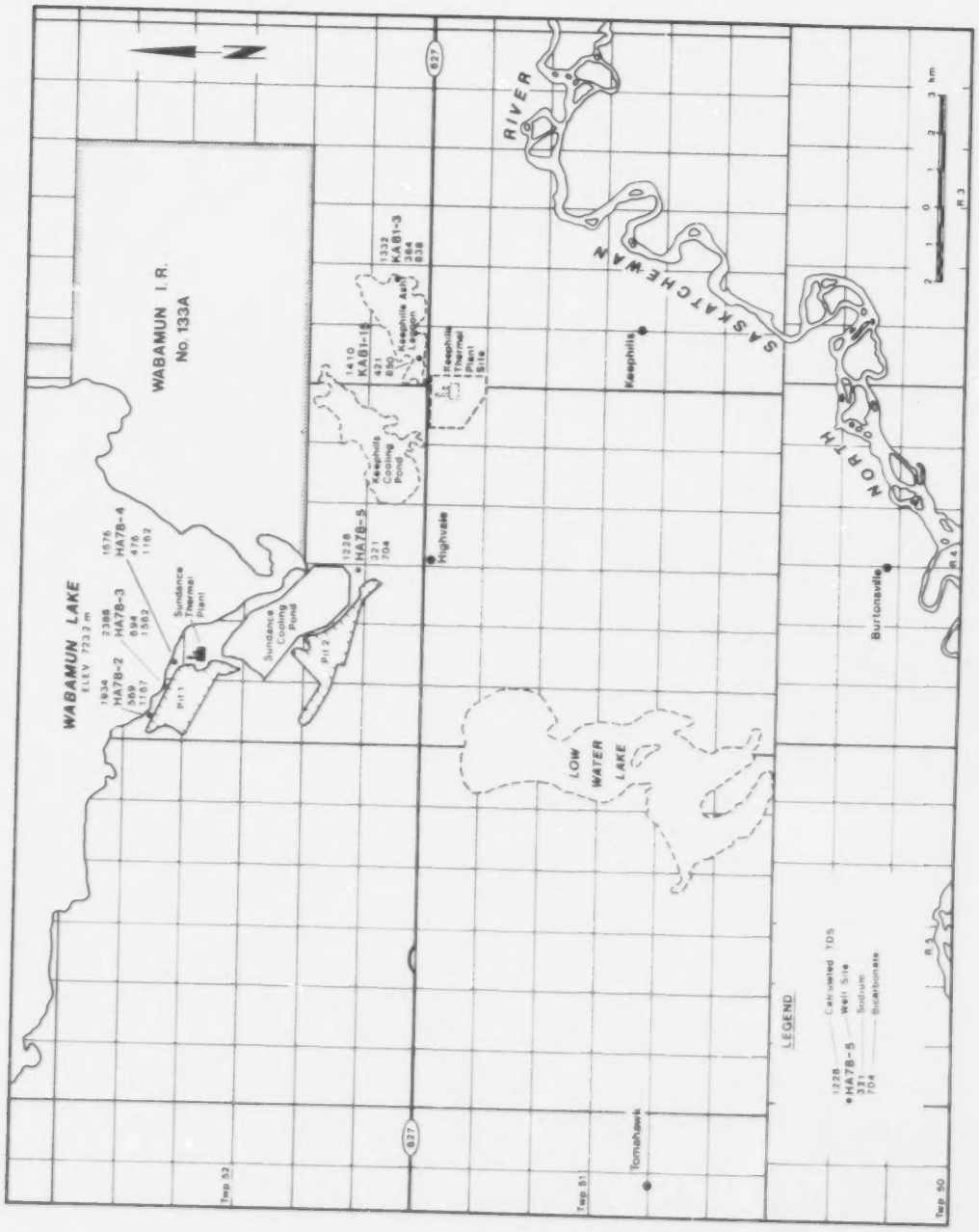

Figure 31. Concentration of total dissolved solids, sodium and bicarbonate in groundwater from the Scollard Member sandstone.

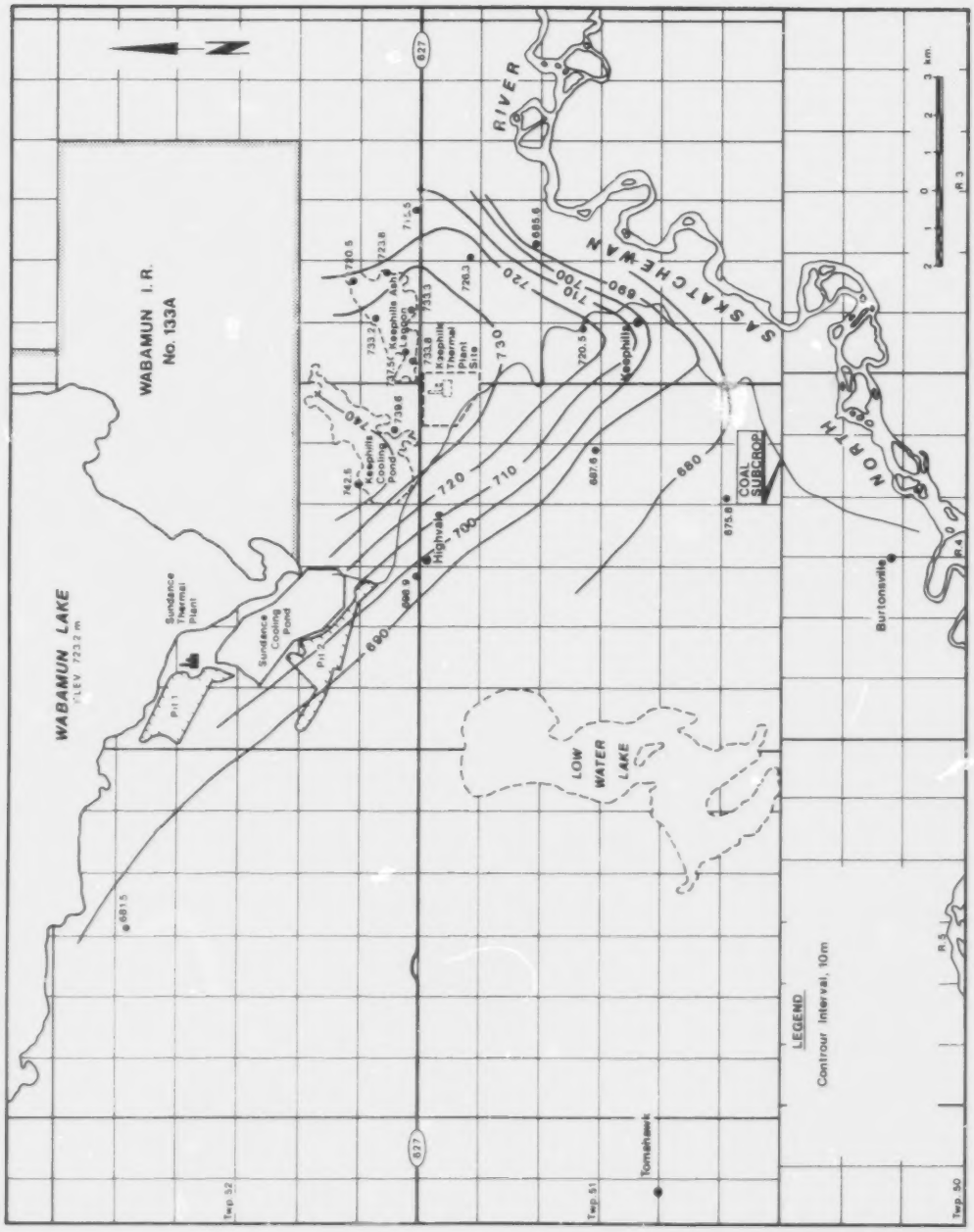

Figure 32. Piezometric surface map for the sandstone of the Upper Horseshoe Canyon Formation.

Lake Wabamun may serve as a source of recharge for this unit in the western part of the study area. That is, Lake Wabamun may be acting as a discharge zone for the shallow, local flow system in the eastern part of the study area, and as a recharge source for the deeper, regional flow system.

The only stable isotope sample available for this stratigraphic unit is from Site KA81-13, which is situated in the area of shallow cover. It indicates that the recharge in this area is meteoric in origin. There are, however, no data available as to the source of recharge elsewhere for this unit.

In water from sandstone of the Upper Horseshoe Canyon the dominant ionic components are sodium and bicarbonate, with TDS ranging from 900 to 1500 mg/L (Figures 33 and 34). The relatively low salinity of the water from this unit may be a reflection of the local nature of the flow system. It appears that the chemical characteristics of water from this aquifer are taken from the recharge area near the sandstone subcrop, as opposed to being inherited from water moving vertically downward through overlying material. Consequently, the chemical characteristics of sandstone of the Upper Horseshoe Canyon are more like those of the much shallower overburden sandstone unit than would be expected based on the great depth of the sandstone of the Upper Horseshoe Canyon over much of the study area. Sodium concentrations range from 250 to 350 mg/L, and bicarbonate from 350 to 650 mg/L (Figure 34). Sulfate concentrations are highest (greater than 200 mg/L) where this unit occurs at shallow depths (recharge area) and are lower (less than 50 mg/L) down gradient.

Eleven samples from sandstone of the Upper Horseshoe Canyon Formation have been analysed using WATEQF. The mean gypsum saturation index value is -3.161, with a standard deviation of 0.923 (n = 11). Individual values range from -4.39 to -1.99. Modified selectivity coefficient values for this sandstone have a mean of 2.648 (standard deviation = 1.809, n = 11) and range from 0.381 to 5.845.

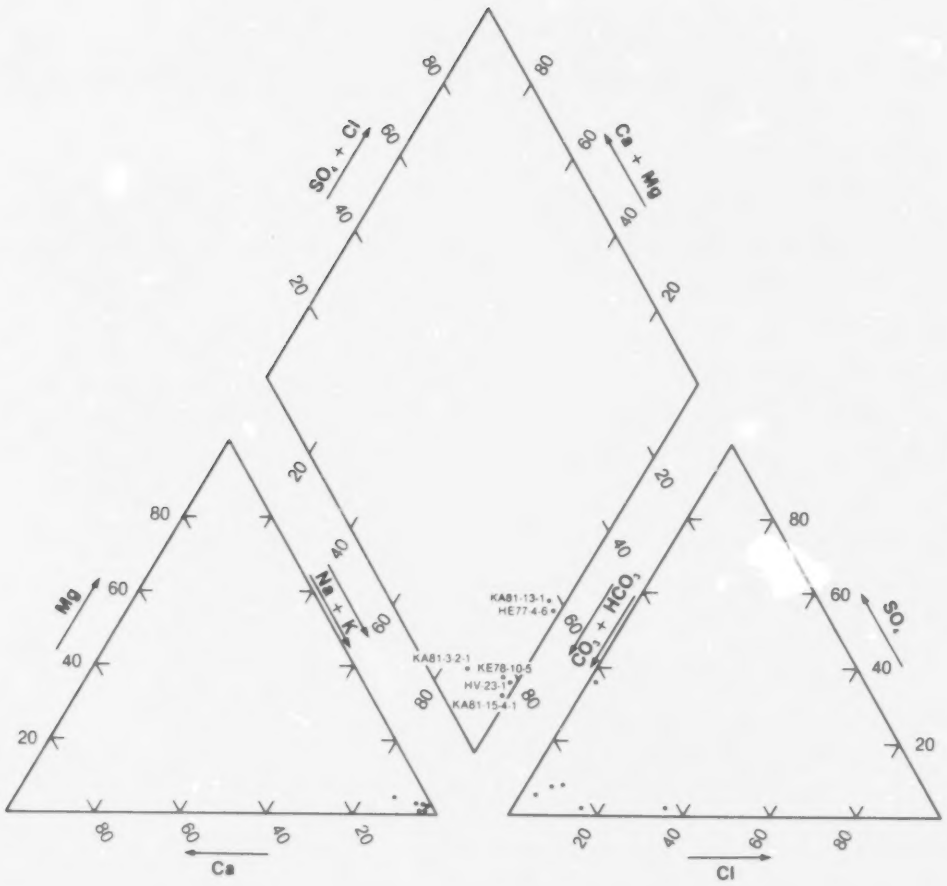

Figure 33. Piper trilinear diagram for groundwater samples from the sandstone of the Upper Horseshoe Canyon Formation.

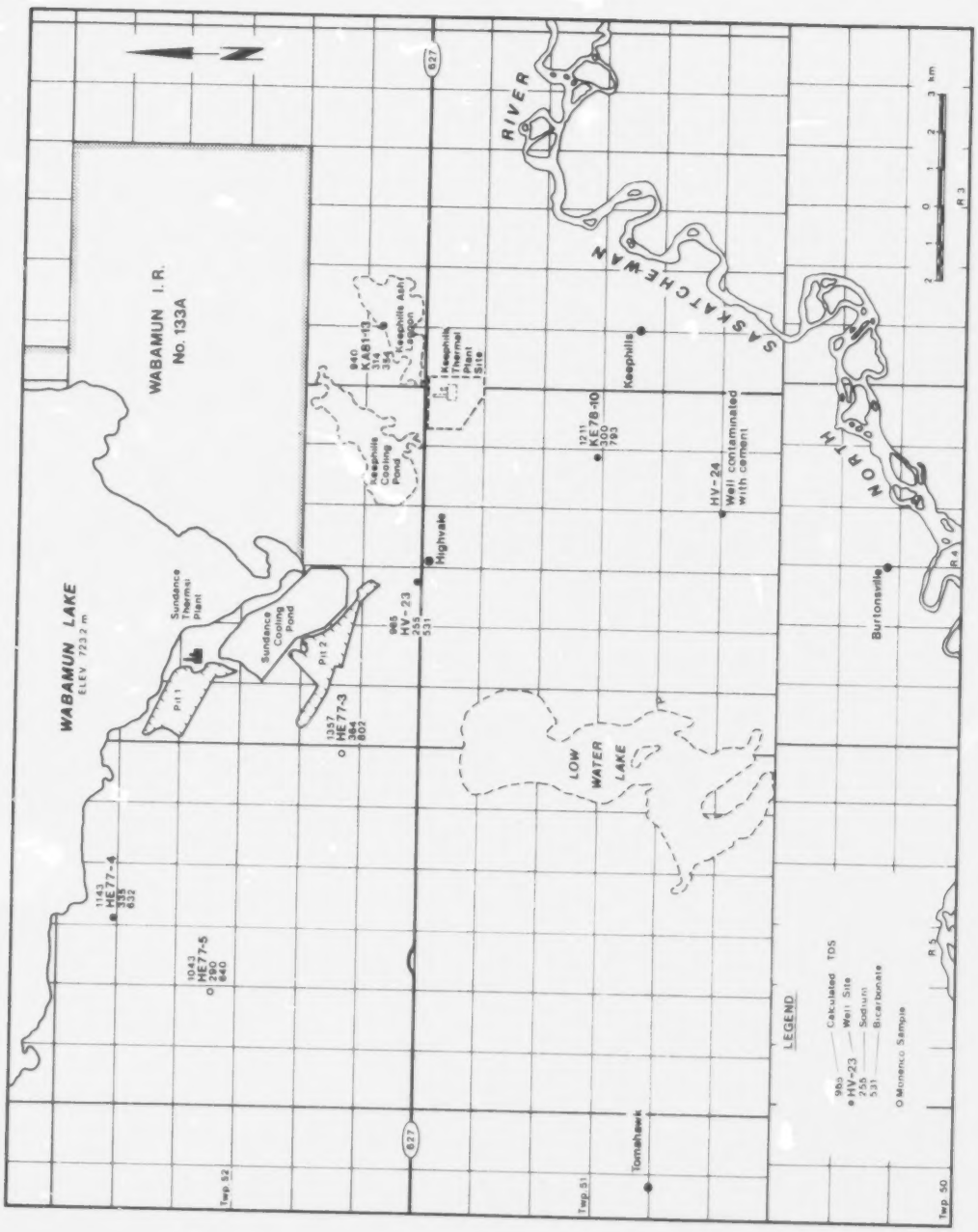

Figure 34. Concentration of total dissolved solids, sodium and bicarbonate in groundwater from the Upper Horseshoe Canyon Formation.

5. DYNAMICS OF GROUNDWATER-FLOW SYSTEM -- EVALUATION OF TRITIUM RESULTS

5.1 INTRODUCTION

It is possible to distinguish relatively recent groundwater, which was recharged after 1953, from groundwater that was recharged prior to 1953 by determining the amount of tritium, the radioactive isotope of hydrogen (atomic mass = 3 amu) in the water. Selected surface and groundwater samples from the Highvale project area were analysed for tritium content to determine the degree of activity or sluggishness of the groundwater-flow system.

The input function for tritium in the recent past can be evaluated by records of tritium content in precipitation and shallow surface water from sites in central Alberta. The tritium content of precipitation has been undergoing an exponential decline since 1963, with concentrations at Edmonton dropping from 4022 TU (mean annual concentration) in 1963 to 478 TU in 1968 (Brown 1970). A measurement from snowmelt in April of 1975 at Horseshoe Lake, Alberta, had a tritium concentration of 90 TU (Wallick in press), and the mean value of precipitation samples at the Battle River site from July 1981 to June 1982 was 47 TU (standard deviation = 30 TU, n = 4), with individual values ranging from 9 TU (November 1981) to 93 TU (July 1981) (Trudell et al. in press). The seasonal range of values is consistent with the expected trend, with maximums occurring in the spring and summer and minimums occurring in the late fall and winter (Gat 1980; Fontes 1980).

The mean tritium concentration of water from surface ponds at the Highvale Site for 1982-83 was 52 TU, with a standard deviation of 23 TU (n = 11). Individual values range from 23 to 90 TU. Soil moisture samples, from 0.5 to 1.5 m in depth had an average tritium concentration of 69 TU (standard deviation = 19 TU, n = 4) during 1982-83. Present-day groundwater recharge at the Highvale Site therefore, should have a tritium concentration of approximately 50 to 90 TU.

5.2 GROUNDWATER MOVEMENT IN THE DRIFT

Nine groundwater samples from the drift at seven sites in the Highvale area were analysed for tritium (Appendix 8.2). However, eight of these samples were collected from wells near the Keephills Ash Lagoon Site, and all nine were from sites beyond the limit of mining. Consequently, the tritium distribution for the drift represented by these samples may not be typical of the tritium content of drift groundwater in the upslope setting represented by the mine area.

Five of the wells sampled contained less than 20 TU indicating that the water was recharged prior to 1953. These wells were completed at depths ranging from 7.7 to 30.6 m, suggesting that the groundwater-flow system even in the shallow drift can be quite sluggish at some sites.

The two sites in the drift that appear on the basis of stable isotope analyses to contain pond water, KA81-5 and KA81-6, have very different tritium contents. At site KA81-5 no tritium was detected in either of two groundwater samples (from 7.7 and 11.2 m depth), indicating pre-1953 recharge. At site KA81-6 the concentration of tritium in the groundwater is 228 TU, from a depth of 9.4 m. This level of tritium probably reflects either undiluted early 1950s or late 1960s water that has been subjected only to radioactive decay, or early 1960s water mixed with low-tritium water. In any case, groundwater in the drift at site KA81-6 was recharged 15 to 30 years ago, and more than 30 years ago at site KA81-5. However, given the similarities in depth and stratigraphy between these two sites, it is likely that the groundwater at site KA81-5 was recharged not a great deal more than 30 years ago.

In addition to KA81-6, only one other site clearly has tritium present in the drift groundwater, HA78-6, at a depth of 5.5 m (tritium concentration = 38 TU). One site, KA81-3, is marginal at 26 TU (from 16.7 m depth). At site HE77-6 a tritium value of 61 TU from 45 m depth conflicts with a concentration of 12 TU from 30 m depth, with the deeper sample probably having been contaminated at

some point, either by drilling fluid during construction or later during sampling.

In summary, at four of seven sites in the drift the groundwater was recharged prior to 1953. Of the remaining three sites, two definitely contain water recharged since 1953 and one is borderline. Overall, these findings indicate that groundwater movement in the drift at the Highvale Site is relatively sluggish.

5.3 GROUNDWATER MOVEMENT IN BEDROCK UNITS

Nine tritium analyses are available for bedrock overburden in the Highvale study area (Appendix 8.2), including one from the siltstone of Unit D, two from the shale of Unit C, and six from the sandstone of Unit B. Two of the three analyses from Units C and D, which have tritium concentrations of 38 and 43 are interpreted to reflect atmospheric tritium contamination during sampling. This may occur when sampling groundwater from fine-grained intervals where several days or weeks are required for a well to recover after having been bailed dry (Trudell et al., in press, pp. 82-83). One sample, however, at a depth of 8.0 m, in Well HE77-2-1, contains a tritium concentration of 30 TU, which indicates that recent groundwater may be present at shallow depths in this horizon.

In the sandstone of Unit B the mean tritium content is 10 TU (standard deviation = 9, n = 6), with individual values ranging from 0 to 23 TU. In all cases the tritium analyses suggest that the groundwater in the sandstone of Unit B is pre-1953 in age, at least for the range of depths sampled (19 to 73 m).

Tritium analyses of 20 samples from the Ardley Coal Zone were completed (Appendix 8.2); four samples are from Coal Seam #1, six from Coal Seam #2, one from Coal Seam #4, and nine from Coal Seam #6 (Appendix 8.2). Fifteen samples represent groundwater recharged prior to 1953, and the remaining five are interpreted to display some degree of contamination.

Three groundwater samples from the sandstone of the Scollard Member were analysed for tritium (Appendix 8.2). In all

samples the tritium concentration was less than 10 TU, indicating that the groundwater in the sandstone of the Scollard Member was recharged prior to 1953.

Five samples from sandstone of the Upper Horseshoe Canyon were analysed for tritium (Appendix 8.2). Two of the samples have a tritium concentration less than 20 TU, indicating pre-1953 water. In the case of the other three samples, the long recovery times of wells required during sampling probably resulted in atmospheric contamination of tritium, giving rise to tritium concentrations of 29 to 47 TU (Trudell et al., in press, pp. 82-83).

6. SUMMARY

6.1 GROUNDWATER-FLOW PATTERNS

1. The regional groundwater-flow pattern has two principal components - one from the uplands in the southwestern part of the study area north toward Lake Wabamun, and the other from the uplands in the east-central part of the study area southeast toward the North Saskatchewan River.
2. Over most of the area vertical hydraulic gradients are directed downward, representing recharge conditions. Groundwater discharge conditions are present at the subcrop of the Ardley Coal Zone and overburden sandstone south of Lake Wabamun, and at some places in Low Water Lake. In all cases hydraulic head in the bedrock overburden and Ardley Coal Zone is greater than the level of Lake Wabamun.
3. The North Saskatchewan River is the regional groundwater drain for both shallow and deep bedrock aquifers in the southern part of the study area.
4. Low Water Lake is in some places a discharge area for shallow bedrock and drift groundwater. In other places it is a source of recharge for bedrock aquifers.
5. In the sandstone of the Upper Horseshoe Canyon Formation, groundwater flow is from the subcrop area southeast of Lake Wabamun, to the southwest and southeast. This flow pattern is related to recharge of the sandstone through the drift cover and from surface ponds. The discharge area for this flow system appears to be along the subcrop of the sandstone in the valley of the North Saskatchewan River.

6.2 GROUNDWATER CHEMICAL CHARACTERISTICS

1. Groundwater in the drift is highly variable both in composition and salinity. In the shallow bedrock, groundwater is primarily of Na^+ - HCO_3^- composition, with low to moderate salinity. Groundwater salinity reaches a maximum of 2000 to 2500 mg/L in the Ardley Coal Zone, and declines somewhat with increased depth. Sandstone beds in the Upper Horseshoe Canyon Formation are the deepest stratigraphic unit studied, at approximately 100 m depth. Groundwater in this unit is also of low to moderate salinity and of Na^+ - HCO_3^- composition.
2. Groundwater in all stratigraphic units is slightly undersaturated to saturated with respect to calcite and dolomite, and undersaturated with respect to gypsum. Ion exchange characteristics of all stratigraphic units except the drift show a strong tendency for dissolved calcium to be exchanged for adsorbed sodium, giving rise to sodium dominated groundwater composition.

6.3 TRACE ELEMENTS

Concentrations of nine trace elements are below maximum allowable levels in all cases. In addition, levels of cadmium, mercury, antimony, and selenium are below detection in almost all samples.

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8. APPENDICES

8.1 TRACE ELEMENT ANALYSES OF GROUNDWATER SAMPLES

Highvale Drift: Trace Element Analysis
All Values in ppb

Sample ID	As	Cd	Co	Cu	Hg	Pb	Sb	Se
Detection Limit	0.4	0.5	0.5	0.5	0.5	0.3	0.5	0.5
Recommended Limit	50.0	5.0	50.0	1000	1.0	50.0	10.0	10.0
HA78-6-2-1	1.2	<0.5	1.2	<0.5	<0.5	0.4	<0.5	<0.5
HE77-6-2-1	3.2	<0.5	0.7	0.7	<0.5	1.0	<0.5	<0.5
HE77-6-3-1	4.3	<0.5	1.0	0.5	<0.5	1.4	<0.5	<0.5
HV-24-1-1	14.0	<0.5	2.5	5.2	<0.5	1.0	<0.5	<0.5
KA81-3-1-1	7.0	<0.5	15.5	0.8	<0.5	<0.5	<0.5	<0.5
KA81-4-2-1	20.5	<0.5	0.9	1.2	<0.5	<0.5	<0.5	<0.5
KA81-5-1-1	3.8	<0.5	14.5	1.0	<0.5	1.2	<0.5	<0.5
KA81-5-2-1	8.4	0.7	20.0	0.8	<0.5	<0.5	<0.5	<0.5
KA81-6-1-1	1.1	<0.5	1.5	1.3	<0.5	0.7	<0.5	<0.5
KA81-16-1-1	1.4	<0.5	1.2	0.7	<0.5	2.2	<0.5	<0.5
KA81-17-1-1	2.7	<0.5	1.7	1.0	<0.5	1.2	<0.5	<0.5
Mean	6.1		5.5	1.3		1.1		
Standard Deviation	6.1		7.3	1.4		0.5		

Highvale Unit D: Trace Element Analysis
All Values in ppb

Sample ID	As	Cd	Co	Cu	Hg	Pb	Sb	Se
Detection Limit	0.4	0.5	0.5	0.5	0.5	0.3	0.5	0.5
Recommended Limit	50.0	5.0	50.0	1000	1.0	50.0	10.0	10.0
HE77-5-1-1	1.4	<0.5	<0.5	1.0	<0.5	1.2	<0.5	<0.5
HV-15-2-1	<0.4	<0.5	1.4	6.0	<0.5	2.5	<0.5	<0.5
HV-15-3-1	0.5	<0.5	1.8	2.9	<0.5	2.2	<0.5	<0.5
HV-22-3-1	0.8	<0.5	<0.5	6.5	<0.5	5.3	<0.5	<0.5
HV-22-4-1	1.5	<0.5	3.3	7.0	<0.5	0.7	<0.5	<0.5
Mean	1.0		2.2	4.7		2.4		
Standard Deviation	0.5		1.0	2.6		1.8		

Highvale Unit C: Trace Element Analysis
All Values in ppb

Sample ID	As	Cd	Co	Cu	Hg	Pb	Sb	Se
Detection Limit	0.4	0.5	0.5	0.5	0.5	0.3	0.5	0.5
Recommended Limit	50.0	5.0	50.0	1000	1.0	50.0	10.0	10.0
HE77-2-1-1	3.2	<0.5	0.8	5.6	<0.5	0.8	<0.5	<0.5
HE77-5-2-1	0.5	<0.5	<0.5	1.0	<0.5	0.5	<0.5	<0.5
HV15-1-1	3.2	0.7	0.7	21.0	<0.5	1.7	<0.5	<0.5
HV-21-2-1	2.1	0.5	1.8	5.0	<0.5	3.5	<0.5	<0.5
HV-22-2-1	7.5	<0.5	1.4	0.5	<0.5	2.4	<0.5	<0.5
Mean	3.3		1.2	6.6		1.8		
Standard Deviation	2.6		0.5	8.4		1.2		

Highvale Unit B: Trace Element Analysis
All Concentrations in ppb (Except Boron in mg/L)

Sample ID	As	Cd	Co	Cu	Hg	Pb	Sb	Se	B
Detection Limit	0.4	0.5	0.5	0.5	0.5	0.3	0.5	0.5	
Recommended Limit	50.0	5.0	50.0	1000	1.0	50.0	10.0	10.0	1.00
HE77-3-1-1	8.5	<0.5	0.7	6.5	<0.5	1.2	<0.5	<0.5	
HE77-4-1-1	0.7	<0.5	1.7	1.2	<0.5	0.8	<0.5	<0.5	0.63
HV-16-1-1	1.2	<0.5	3.0	11.5	<0.5	1.5	<0.5	<0.5	
HV-16-2-1	2.3	<0.5	3.0	6.0	<0.5	1.5	<0.5	<0.5	
HV-16-3-1	2.5	<0.5	4.0	6.0	<0.5	2.7	<0.5	<0.5	
HV-17-4-1	<0.4	<0.5	2.0	5.0	<0.5	0.5	<0.5	<0.5	
HV-19-2-1	7.0	<0.5	0.8	3.0	<0.5	1.3	<0.5	<0.5	
HV-21-1-1	12.0	<0.5	<0.5	3.0	<0.5	<0.3	<0.5	<0.5	
HV-22-1-1	6.0	<0.5	<0.5	8.5	<0.5	1.4	<0.5	<0.5	
HV-23-5-1	9.5	<0.5	0.9	14.5	<0.5	<0.3	<0.5	<0.5	
HV-24-5-1	1.3	<0.5	3.2	2.9	<0.5	2.7	<0.5	<0.5	
HV-24-6-1	15.0	<0.5	2.0	1.8	<0.5	1.1	<0.5	<0.5	
KE78-11-1-1	2.8	<0.5	1.7	1.0	<0.5	2.0	<0.5	<0.5	
KE78-11-2-1	0.5	<0.5	1.5	0.7	<0.5	4.0	<0.5	<0.5	
KE78-11-3-1	0.4	<0.5	<0.5	0.7	<0.5	1.2	<0.5	<0.5	
SB81-1-2-1	2.8	<0.5	<0.5	1.2	<0.5	1.0	<0.5	<0.5	
SB81-2-3-1	2.4	<0.5	0.5	0.5	<0.5	0.4	<0.5	<0.5	
Mean	4.7		1.9	4.4		1.6			
Standard Deviation	4.5		1.1	4.1		1.0			

Highvale Coal Seam #1: Trace Element Analysis
All Concentrations in ppb

Sample ID	As	Cd	Co	Cu	Hg	Pb	Sb	Se
Detection Limit	0.4	0.5	0.5	0.5	0.5	0.3	0.5	0.5
Recommended Limit	50.0	5.0	50.0	1000	1.0	50.0	10.0	10.0
HE77-2-3-1	1.0	<0.5	2.0	6.0	<0.5	0.8	<0.5	<0.5
KE78-12-2-1	1.9	<0.5	1.7	3.6	<0.5	1.4	<0.5	<0.5
HE77-5-3-1	0.4	<0.5	0.9	5.6	<0.5	1.3	<0.5	<0.5
HV23-4-1	2.0	<0.5	1.5	16.5	<0.5	0.7	<0.5	<0.5
Mean	1.3		1.5	7.9		1.0		
Standard Deviation	0.8		0.5	5.8		0.4		

Highvale Coal Seam #2: Trace Element Analysis
All Values in ppb

Sample ID	As	Cd	Co	Cu	Hg	Pb	Sb	Se
Detection Limit	0.4	0.5	0.5	0.5	0.5	0.3	0.5	0.5
Recommended Limit	50.0	5.0	50.0	1000	1.0	50.0	10.0	10.0
HV-13-1-1	3.6	<0.5	1.2	3.5	<0.5	1.5	<0.5	<0.5
HV-17-2-1	<0.4	<0.5	1.8	5.0	<0.5	0.6	<0.5	<0.5
HV-17-3-1	<0.4	<0.5	5.0	4.5	<0.5	1.2	<0.5	<0.5
HV-23-3-1	3.9	<0.5	<0.5	1.7	<0.5	<0.3	<0.5	<0.5
KE-78-11-4-1	1.4	<0.5	1.2	4.0	<0.5	6.2	<0.5	<0.5
KE-78-11-5-1	0.5	<0.5	<0.5	1.5	<0.5	1.2	<0.5	<0.5
HV-78-2-4-1	1.2	<0.5	0.5	2.1	<0.5	1.1	<0.5	<0.5
Mean	2.1		1.9	3.2		2.0		
Standard Deviation	1.5		1.8	1.4		2.1		

Highvale Coal Seam #6: Trace Element Analysis
All Values in ppb

Sample ID	As	Cd	Co	Cu	Hg	Pb	Sb	Se
Detection Limit	0.4	0.5	0.5	0.5	0.5	0.3	0.5	0.5
Recommended Limit	50.0	5.0	50.0	1000	1.0	50.0	10.0	10.0
HV-17-1-1	2.9	<0.5	20.0	6.5	<0.5	2.8	<0.5	<0.5
HV-19-1-1	2.1	<0.5	1.7	0.8	<0.5	3.0	<0.5	<0.5
HV-23-2-1	7.0	<0.5	2.2	3.5	<0.5	0.9	<0.5	<0.5
HV-24-3-1	1.1	<0.5	1.4	4.0	<0.5	1.5	<0.5	<0.5
HA78-3-2-1	1.2	<0.5	2.7	1.5	<0.5	4.0	<0.5	<0.5
HA78-4-2-1	0.6	<0.5	0.5	0.5	<0.5	<0.3	<0.5	<0.5
HA78-5-2-1	0.6	<0.5	0.7	4.7	<0.5	0.6	<0.5	<0.5
HA78-6-1-1	<0.4	<0.5	0.5	1.0	<0.5	0.4	<0.5	<0.5
HE77-5-4-1	0.4	<0.5	1.2	2.2	<0.5	2.0	<0.5	<0.5
KE78-9-3-1	0.8	<0.5	2.5	2.5	<0.5	1.0	<0.5	<0.5
KE78-11-6-1	2.6	<0.5	1.0	4.2	<0.5	3.0	<0.5	<0.5
Mean	1.9		3.1	2.8		1.9		
Standard Deviation	2.0		5.6	1.9		1.2		

Trace Element: Highvale
Stratigraphic Unit: Scollard Member Sandstone (Below Coal Zone)
All Concentrations in ppb (Except Boron, ppm)

Well ID	As	Cd	Co	Cu	Hg	Pb	Sb	Se	B
Detection Limit	0.4	0.5	0.5	0.5	0.5	0.3	0.5	0.5	
Recommended Limit	50.0	5.0	50.0	1000	1.0	50.0	10.0	10.0	1.00
HA78-3-1-1	0.4	<0.5	2.5	2.1	<0.5	1.3	<0.5	<0.5-	
KA81-15-4-1	5.0	<0.5	0.5	3.7	<0.5	2.0	<0.5	<0.5-	
HA78-4-1-1	4.8	<0.5	0.5	1.0	<0.5	0.3	<0.5	<0.5-	
HA78-5-1-1	0.4	<0.5	0.5	0.7	<0.5	1.2	<0.5	<0.5-	
KA81-3-2-1	7.8	<0.5	1.2	17.5	<0.5	1.4	<0.5	<0.5	0.15
Mean	3.7	0.5	1.0	5.0	0.5	1.2	0.5	0.5	0.15
Standard Deviation	3.2	0.5	0.9	7.1	0.5	0.6	0.5	0.5-	

8.2 TRITIUM ANALYSED OF GROUNDWATER SAMPLES FROM THE HIGHVALE PROJECT AREA

Highvale Drift

Sample ID	Date	Tritium Units
HE77-6-2-1	Aug 26/82	12
HE77-6-3-1	Aug 26/82	61
HA78-6-2-1	Aug 26/82	38
KA81-3-1-1	Sept 17/82	26
KA81-5-1-1	July 27/82	0
KA81-5-2-1	Aug 27/82	0
KA81-6-1-1	Sept 17/82	228
KA81-16-1-4	Aug 19/82	6
KA81-17-1-1	Aug 19/82	7

Mean - 42

Standard Deviation - 73

Highvale Unit D Siltstone/Shale Overburden

Sample ID	Date	Tritium Units
HE77-5-1-1	July 23/82	43

Highvale Unit C Shale/Siltstone Overburden

Sample ID	Date	Tritium Units
HE77-2-1-1	July 21/82	30
HE77-5-2-1	July 21/82	38

Highvale Unit B Sandstone/Siltstone

Sample ID	Date	Tritium Units
HV-21-1-1	Sept 30/82	9
HE77-3-1-1	Aug 20/82	23
HE77-4-1-1	July 13/82	19
KE78-11-1-1	Aug 13/82	8
KE78-11-2-1	Aug 13/82	1
KE78-11-3-1	Aug 13/82	0

Mean - 10

Standard Deviation - 9

Highvale Coal Seam #1

Sample ID	Date	Tritium Units
HE77-2-3-1	July 20/82	30
HE77-4-2-1	July 14/82	27
KE78-12-2-1	July 30/82	59
HE77-5-3-1	Sept 14/82	10

Mean - 32

Standard Deviation - 20

Highvale Coal Seam #2

Sample ID	Date	Tritium Units
HV23-3-1	Sept 30/82	0
HE77-2-4-1	July 16/82	12
HE77-4-3-1	July 16/82	20
HA78-2-4-1	Aug 5/82	3
KE78-11-4-1	Aug 17/82	0
KE78-11-5-1	Aug 17/82	0

Mean - 6

Standard Deviation = 8

Highvale Coal Seam #4

Sample ID	Date	Tritium Units
HA78-3-3-1	Aug 11/82	4

Highvale Coal Seam #6

Sample ID	Date	Tritium Units
HE77-2-5-1	July 16/82	38
HE77-4-4-1	July 15/82	23
HE77-5-5-1	Sept 14/82	32
HA78-3-2-1	Aug 11/82	0
HA78-4-2-1	Aug 24/82	12
HA78-5-2-1	Aug 25/82	8
KE78-11-6-1	Aug 18/82	20
KE78-11-7-1	Aug 18/82	8
KE78-12-4-1	Aug 4/82	0

Mean - 16

Standard Deviation - 14

Scollard Member Sandstone (Below Coal Zone)

Sample ID	Date	Tritium Units
HA78-3-1-1	Aug 6/82	9
HA78-4-1-1	Aug 24/82	5
KA81-15-4-1	Aug 12/82	0

Upper Horseshoe Canyon Sandstone

Sample ID	Date	Tritium Units
KA81-13-1-1	Aug 12/82	47
HE77-4-6-1		15
HV23-1-1		9
HV24-2-1		38
KE78-10-5-1		29

Mean - 28

Standard Deviation - 16

8.3 SINGLE WELL RESPONSE TEST RESULTS - HIGHVALE

Site	Hydraulic Conductivity (m/s) Rising Head	Falling Head	Bail Test
15-1	7.17×10^{-7}	8.6×10^{-7}	
15-3	4.80×10^{-5}	4.92×10^{-5}	
16-3	5.86×10^{-9}		
17-1	2.15×10^{-6}	2.39×10^{-6}	
17-2	3.07×10^{-6}	3.16×10^{-6}	
17-3	1.21×10^{-6}	1.76×10^{-6}	
17-4	1.16×10^{-5}	1.44×10^{-5}	
19-1	3.54×10^{-7}	2.71×10^{-7}	
19-3	2.37×10^{-6}	1.63×10^{-6}	
		2.36×10^{-7}	
22-1		1.01×10^{-8}	
22-2			3.94×10^{-8}
22-3	3.16×10^{-6}	2.99×10^{-6}	
22-4	1.11×10^{-5}	6.82×10^{-6}	
23-2		5.12×10^{-8}	
23-3	3.32×10^{-7}	5.31×10^{-7}	
23-4	8.28×10^{-8}	4.35×10^{-8}	
23-5	4.67×10^{-7}	4.48×10^{-7}	
24-1		1.92×10^{-7}	
HE77-4-6	1.84×10^{-7}	2.0×10^{-6}	
HA78-2-1		5.25×10^{-7}	
HA78-3-1	6.34×10^{-7}	8.96×10^{-7}	
HA78-4-1	3.73×10^{-7}	3.59×10^{-7}	